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# TECHNICAL ASPECTS OF DETECTION AND INSPECTION CONTROLS OF A NUCLEAR WEAPONS TEST BAN

## SUMMARY-ANALYSIS OF HEARINGS
APRIL 19, 20, 21, AND 22, 1960

JOINT COMMITTEE ON ATOMIC ENERGY
CONGRESS OF THE UNITED STATES

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## FOREWORD

This summary-analysis of hearings on "Technical Aspects of Detection and Inspection Controls of a Nuclear Weapons Test Ban" held by the Special Subcommittee on Radiation and the Subcommittee on Research and Development, April 19–22, 1960, was unanimously approved by all members of both subcommittees. It was subsequently approved by all members of the Joint Committee on Atomic Energy for publication as a full committee report.

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# SUMMARY-ANALYSIS OF PUBLIC HEARINGS ON TECHNICAL ASPECTS OF DETECTION AND INSPECTION CONTROLS OF A NUCLEAR WEAPONS TEST BAN

## CHAPTER I. INTRODUCTION

The possibilities and problems of detection and identification of nuclear test explosions, as a part of a test ban control system discussed at Geneva for the past 18 months, have become questions of great national and international importance. The summit meetings beginning May 16, 1960, and followup discussions at Geneva and elsewhere in succeeding weeks and months, will undoubtedly consider these matters extensively.

A large part of the basis of a control system to support a test ban treaty or international agreement depends on technical data of a rather complicated nature. Such technical information can and should have a profound effect on the establishment of an adequate control system. For example, the report of the original Conference of Experts at Geneva in July–August 1958, on which the test ban negotiations are based, has been found to be highly dependent on data derived from the single U.S. "Rainier" underground test shot in September 1957, which subsequent tests have proved to be inadequate.

In order to clarify the technical basis of a test ban control system, the Joint Congressional Committee on Atomic Energy, through its Special Subcommittee on Radiation and Subcommittee on Research and Development, held 4 days of public hearings on April 19, 20, 21, and 22, 1960. It was intended that the hearings would help dispel many of the confusing reports and conflicting statements as to technical problems and possibilities which may or may not exist as to means of detection and identification of nuclear tests.

The hearings covered the entire scope of nuclear test detection and control, including the basis of the original proposed Geneva control system of 180 stations; analysis of the basis for improvement of the Geneva system under present knowledge; consideration of means of concealment and muffling of tests; discussion of basis of "on-site" inspections; consideration of detection and identification of nuclear tests in outer space; discussion of technical significance of further weapons development through clandestine tests and review of research and development programs aimed at improving capabilities for detection and identification of nuclear tests.

The subcommittee made every effort to emphasize the technical aspects of the test ban system, and to avoid discussions involving general policy or political and philosophical aspects of disarmament and a test ban. Naturally, in the discussion of control systems questions of policy inevitably arose. However, insofar as possible, the discussion was confined to the technical aspects of such questions.

In accordance with past practice in the fallout hearings, the subcommittees selected a representative group of the leading scientists

and technical experts in this field. Each witness was selected on the basis of his personal competence and his degree of knowledge and experience in the individual topics on which he testified. Many of the witnesses were members of or consultants to the technical delegations to the conferences and panels discussed in these hearings. Others were selected for their skills and experience in the field application of the techniques discussed throughout the hearings. A list of all witnesses is attached as appendix I. A detailed biography of each witness is included in the print of the complete hearings.

The Joint Committee in its preparation for, and conduct of, the hearings received the cooperation of the Atomic Energy Commission, the Department of Defense, and particularly the Air Force Technical Applications Center, and various individual scientists and scientific organizations of widely differing views.

One of the highlights of the series of hearings was a panel discussion on the entire question of the feasibility and capability of test ban control systems. The panel members were a selected group from the scientific community whom the committee felt represented the most complete spectrum of opinion on these vital questions. It was considered by the committee that the bringing together of such a group would tend to pinpoint the major conflicts of opinion which exist today concerning the problem of providing an adequate control system. The panel consisted of the following scientists and engineers:

Dr. Roland Beers, seismic consultant, Troy, N.Y.
Dr. Hans Bethé, Physics Department, Cornell University, Ithaca, N.Y.
Dr. Harold Brown, Lawrence Radiation Laboratory, Livermore, Calif.
Dr. Dean S. Carder, Chief Seismologist, U.S. Coast and Geodetic Survey, Washington, D.C.
Dr. Alvin C. Graves, Los Alamos Scientific Laboratory, Los Alamos, N. Mex.
Dr. Richard Latter, Rand Corp., Santa Monica, Calif.
Dr. Jack E. Oliver, Lamont Geological Observatory, Columbia University, New York, N.Y.
Dr. Jay Orear, Physics Department, Cornell University, Ithaca, N.Y.
Dr. Richard E. Roberts, Carnegie Institution, Washington, D.C.
Dr. Carl F. Romney, Headquarters USAF, Air Force Technical Applications Center, Washington, D.C.
Dr. Edward Teller, Lawrence Radiation Laboratory, Livermore, Calif.
Dr. Harold Urey, University of California, Scripps Institute of Oceanography, La Jolla, Calif.

In order for the layman to understand the technical aspects of a control system, it is necessary that certain technical terms and concepts be defined in layman's language. To assist the layman, a number of technical terms and concepts have been defined and appear in appendix II. To further assist in reviewing the summary-analysis certain key definitions and concepts will be discussed below.

The nub of the problem of detection and identification of underground nuclear tests is, first, to detect the event on a seismograph; second, to distinguish the difference in the recorded signature of a nuclear event and the recorded signature of a natural earthquake. The following definitions may prove helpful in a consideration of this problem:

*1. Yields of nuclear weapons*

(*a*) *Kiloton:* Nuclear explosive energy release equivalent to 1,000 tons of the chemical high explosive, TNT. The nuclear bomb detonated at Hiroshima, Japan, in World War II was the equivalent in size to 20 kilotons of TNT.

(*b*) *Megaton:* Nuclear explosive energy release equivalent to 1,000,000 tons of the chemical high explosive TNT.

(*c*) *Low yield weapons:* Those nuclear weapons ranging in yields of approximately 20 kilotons and below. This class is often referred to as "tactical weapons."

(*d*) *High yield weapons:* Those nuclear weapons ranging in yields of approximately 50 kilotons and more, to include megaton yields. This class is often referred to as "strategic weapons."

(*e*) *Fractional kiloton weapons:* The term applied to those "tactical weapons" of a yield which is a fractional part of 1 kiloton. This class of weapons is rated in yield ranges of tons rather than kilotons.

*2. Detection instruments*

(*a*) *Seismograph:* An instrument for detecting and recording small vibrations in the earth's crust. The detector portion, called a seismometer, usually consists of a mass suspended from a frame, either by springs or as a pendulum, in such a manner as to tend to remain in one position while the earth-mounted frame moves with the earth. The relative motion of the frame and mass is usually magnified and recorded as a seismic disturbance either natural or manmade. Various types of seismographs exist, including seismographs for long periods, intermediate periods, short periods, and high frequency.

(*b*) *Magnetometer:* An instrument for measuring the natural magnetic field of the earth to discover any distortion in this field by manmade ferrous articles, equipment, pipes, etc.

(*c*) *Electromagnetic induction detectors:* An instrument which radiates a low frequency electromagnetic field and is sensitive to any distortion in this field due to the presence of conducting material such as iron or copper pipe, wire, land mines, etc.

*3. Types of rock or earth considered in these hearings in which nuclear tests or earthquakes may take place*

(*a*) *Nevada tuff:* A weakly cemented, rather crumbly rock, formed from volcanic ash. The underground nuclear explosions of Hardtack II, as well as the Rainier explosion, occurred in this rock. Experiments indicate the explosions in this rock produce stronger seismic signals than are produced by the same size explosions in salt or granite.

(*b*) *Granite:* A natural igneous rock formation of visably crystalline texture. It is very hard and is believed to be more elastic to nuclear detonations than Nevada tuff resulting in weaker seismic signals.

(*c*) *Salt:* A colorless or white crystalline compound, chemically designated as sodium chloride, occurring abundantly in deposits in the earth in solid form. It would be similar to granite in relation to nuclear detonations.

(*d*) *Limestone:* A rock consisting chiefly of calcium carbonate. It is sometimes formed by chemical precipitation, but chiefly by accumulation of organic remains such as shells and coral.

*4. Decoupling (muffling), coupling, and tamping*

(*a*) *Decoupling:* The process of reducing the size of the seismic signals from an underground explosion by detonation of the explosive in a large hole deep underground.

(*b*) *Coupling:* In this report, coupling refers to that fraction of the total energy released in an underground explosion which is transformed into seismic waves in the earth. The greater the coupling of

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a particular explosion the larger will be the seismic waves and the easier it will be to detect by seismographs at some distance from the explosion.

(*c*) *Rainier coupling:* The Rainier shot (1.7 kilotons) conducted 900 feet underground in intimate contact with Nevada tuff on September 19, 1957, was estimated to have transmitted about 2 percent of its energy into seismic waves. This observed degree of energy transformation from the explosion to seismic waves in the earth (coupling) has been taken as a standard of reference for subsequent calculations of seismic signals generated by underground nuclear explosions.

(*d*) *Tamped shot:* An underground explosion detonated in close contact with the surrounding earth or rock so as to transmit to the earth or rock the largest possible fraction of its energy.

It was apparent to the subcommittees that there is a wide divergence in the degree of knowledge concerning test control systems. Moreover, much of the technical data concerning test control systems is drawn from purely theoretical calculations, while some have an experimental basis. Many of the "practical" aspects involving application of theoretical data have yet to be investigated on an extensive basis.

However, the hearings of the subcommittees did serve to narrow the differences of opinion as to certain scientific facts and judgments. Specifically, there was general agreement as to the following:

1. The Geneva control system of 180 stations will require augmentation and improvement to restore the capability for detection and identification of underground seismic events to the value of 5 kilotons estimated by the 1958 Conference of Experts (hereinafter EXPERTS).

2. It is possible to increase the difficulty of detection and identification of underground seismic events by decoupling nuclear explosions by a factor of up to 300.

3. To establish a capability for the Geneva control system to detect and identify underground seismic events of yield equivalent to that of a 20-kiloton fully decoupled explosion, it will be necessary to increase greatly the number of stations and to improve the instruments and techniques of seismic detection.

4. A vigorous and sustained program of research and development is necessary to improve our instruments and our techniques of detection, identification, and inspection of underground nuclear explosion tests.

5. An increase in the number of stations in the Geneva control system, in order to lower the threshold of underground seismic events which it can detect and identify, will result in a considerable increase in the number of unidentified events which may require inspection.

Certain differences as to scientific facts and judgments were also brought out. These included:

1. The degree and practicality of decoupling by means of large cavities;

2. The extent and practicality of further improvements in detection networks and devices;

3. The significance of further weapons development through clandestine tests.

The subcommittees were also impressed by the importance of the time factor in relation to nuclear test cessation. The United States has not tested any nuclear weapons since its Hardtack II series in the

fall of 1958. It appears from the testimony that at least for the next several years it will not be possible to identify underground events whose seismic signals record the equivalent of a nonmuffled nuclear explosion of 20 kilotons or less, although they may be detected. Further, it appears that for this same time period it will not be possible to detect muffled tests of 100 kilotons or more set off deep underground in large cavities. Therefore, it seems that for the next several years and possibly thereafter there could be a race between improved means of detection and identification as against improved means of concealing and muffling nuclear tests.

# CHAPTER II. SUMMARY

## THE EXPERTS' SYSTEM

The system of 180 control posts recommended by the Conference of Experts, August 1958 [1] (hereafter referred to as the EXPERTS) was designed primarily with the detection and identification of nuclear explosions underground, underwater, and in the atmosphere up to altitudes of about 30 miles. The Conference concluded that by the methods of acoustic, seismic, and electromagnetic detection and nuclear debris sampling, supplemented in some cases by on-site inspection, there would be a good probability of detecting and identifying nuclear explosions of 1 kiloton or more in the atmosphere up to altitudes of 6 miles and a good probability of detecting but not always identifying nuclear explosions taking place between altitudes from 6 to about 30 miles. It was recognized that there were large areas over the oceans, particularly in the Southern Hemisphere, where the detection capability of the control system would be somewhat degraded as a result of the large distances between control posts.

For underwater explosions deep in open oceans the EXPERTS concluded that by means of the hydroacoustic, and seismic nuclear explosions of 1 kiloton or more could be detected and identified with a good probability.

The EXPERTS considered that the problem of detecting and identifying underground explosions is one of the most difficult, and that to a large extent it determines the characteristics of the network of control posts. They concluded that, by the seismic method alone, underground explosions within the continental areas of the world could be detected and located down to yields in the 1 kiloton to 5 kiloton range if the 180 control posts were established at intervals of 1,000 kilometers (600 miles) in seismic regions and 1,700 kilometers (1,000 miles) in aseismic regions.

It was realized that the seismic method alone could not identify underground nuclear explosions. It was concluded that the seismic system could, however, identify about 90 percent of the earthquakes which produce seismic signals equivalent to an underground explosion of 5 kilotons or more under Rainier coupling conditions and a few percent of the earthquakes between 1 and 5 kilotons equivalent. This would leave annually a thousand or more earthquakes throughout the world between 1 and 5 kilotons equivalent (Rainier coupling) and about 100 earthquakes of 5 kilotons equivalent and above (Rainier coupling) which could be suspected of being nuclear explosions. The Soviets estimated the number above 5 kilotons equivalent as 20. Thus, the EXPERTS' report contains the estimate of unidentified events above 5 kilotons equivalent as 20 (U.S.S.R. estimate) to 100

[1] Report of the Conference of Experts To Study the Methods of Detecting Violations of a Possible Agreement on the Suspension of Nuclear Tests. The Conference took place July–August 1958 in Geneva between scientific representatives from the United States, the United Kingdom, Canada, and France on one side and the U.S.S.R., Poland, Czechoslovakia, and Romania on the other. The report dated August 20, 1958, is contained in the printed hearings.

(U.S.-U.K. estimate) on all continents annually. (These numbers of unidentified events were subsequently found to be too low as a result of new seismic data from a later series of tests, Hardtack II.)

(On-site inspection is the best method known for identifying a seismic event which has been detected but not identified as either an earthquake or a nuclear explosion.)

The EXPERTS recognized the possibility that for underground nuclear explosions in rock media other than Nevada tuff, coupling to the earth might be larger or smaller by a factor of a few and hence such explosions might be either more or less difficult to detect.

In the case of nuclear explosions at high altitude and in space the 1958 Conference of Experts noted that various methods for detecting such explosions were possible—e.g., the detection of gamma rays and neutrons—but made no recommendations for including such techniques in the EXPERTS' system.

### DETECTION AND IDENTIFICATION OF UNDERGROUND NUCLEAR TESTS

As a result of data from the Hardtack II series of underground nuclear explosions conducted by the United States after the 1958 Conference of Experts report, the following conclusions were made by the Berkner Panel:[2]

(*a*) The estimates of the EXPERTS concerning identification of underground nuclear explosions of 5 kilotons or more apply more accurately to yields of 20 kilotons or more.

(*b*) Estimates of the numbers of earthquakes equivalent to various nuclear yields below 20 kilotons must be revised upward by considerable amounts.

(*c*) The annual number of unidentified events above 1 kiloton equivalent would exceed that estimated by the EXPERTS by about a factor of 10.

In addition, subsequent theoretical predictions increased the estimated degree of decoupling (muffling) possible by firing nuclear devices in large underground cavities from a factor of 2 to 3 as agreed at the EXPERTS' Conference up to a factor of 300. This was confirmed experimentally by the Cowboy series of small chemical explosions.

The Berkner Panel recommended in March 1959 an intensive program of research and development to improve methods of seismic detection. In addition they recommended the following specific immediate improvements to the Geneva system to restore the original capability of detection and identification estimated by the EXPERTS:

(*a*) Large arrays of up to 100 seismometers at each control post;

(*b*) Long period seismographs at every control post;

Furthermore, the Berkner Panel recommended the following techniques be considered for urgent research and development:

(*a*) Seismometers in deep holes (thousands of feet);

(*b*) Unmanned seismic stations at spacings of 100 to 200 miles between the wider spaced control posts of the EXPERTS' system.

Technical Working Group II, consisting of technical experts from the United States, the United Kingdom, and the U.S.S.R. met in

[2] The Berkner Panel was a panel on seismic improvement consisting of a number of scientists under the chairmanship of Dr. Lloyd V. Berkner. It was appointed by the Special Assistant to the President for Science and Technology on Dec. 28, 1958. It reported its findings on Mar. 16, 1959, which were made public on June 12, 1959. The report is contained in the printed hearings.

Geneva during November and December 1959 to reexamine the problem of underground tests and to attempt to reach agreement on techniques and instrumentation that might improve detection and identification of seismic events. The U.S. report to the Technical Working Group II set forth worldwide earthquake statistics and criteria for identification.

Based on these statistics and criteria, preliminary calculations were made of the estimated annual number of continental seismic events in the U.S.S.R. and the number that would not be identifiable by seismic instruments.[3] It was calculated that about 100 naturally occurring seismic events per year occur in the Soviet Union above magnitude 4.75 of which an estimated 70 could not be identified as earthquakes by seismographs of the Geneva system.

A formula was then established for determining a quota of on-site inspections on the basis of 20 percent of all estimated earthquakes above magnitude 4.75 (100). An alternative basis was 30 percent of the estimated unidentified events above magnitude 4.75 (70). The quota obtained by either method was about 20 on-site inspections to be permitted annually in the Soviet Union and was contained in the U.S. February 11, 1960, proposal at Geneva.

During the hearings Dr. Richard Latter of the Rand Corp. presented for the first time the expected performance of the Geneva system in the U.S.S.R. This report using less rigorous criteria for identification of earthquakes, and applying these criteria only to events within 600 miles of each control post, where seismic data are more reliable, stated that the annual number of unidentified events in the Soviet Union would be 53.

This report covered the effect of increasing the number of seismic control posts in the Soviet Union from 21 to 30. If the 30 stations were installed, Rand estimated that only 9 earthquakes per year would remain unidentified at magnitude 4.75 (20 kilotons, Rainier coupling) and 36 unidentified events per year at magnitude 4.35 (5 kilotons, Rainier coupling). Rand concluded that such a system would essentially restore the capability estimated by the 1958 Conference of Experts. The Rand study did not take into consideration of effects of decoupling.

The estimated cost of the complete Geneva control system was reported by the Advanced Research Projects Agency of the Department of Defense to be $1 billion in round numbers with an annual operating cost of about one-quarter of a billion dollars. A contractor study presented an estimate of $1 to $5 billion for installation of 22 stations of the Geneva system seismic network in the U.S.S.R. alone.[4]

## MEANS OF CONCEALING UNDERGROUND NUCLEAR TESTS

Seismic signals from underground nuclear tests can be reduced by decoupling in large holes deep underground. Witnesses agreed that decoupling factors of up to 120 were proven experimentally in Cowboy Series. They further agreed that an additional decoupling factor of 2½ between salt and tuff exists because of the difference in the physical properties of these two materials. Finally, they were in agreement that these two factors combined resulted in an overall

[3] These calculations were made by the Office of the Special Assistant to the President for Science and Technology utilizing the best information available at the time (Jan. 6, 1960).

[4] See chs. III and V.

factor of 300 reduction in seismic signals from a decoupled shot in salt compared to a tamped shot in Nevada tuff. These decoupling tests were conducted in the fall of 1959 by the AEC in a Louisiana salt dome. Holes in diameter of 12 and 30 feet were used. These chemical explosions ranged from 20 to 2,000 pounds in size.

Deep large cavities can be washed in underground salt domes of which some 200 or more exist in the United States and an unknown number in the U.S.S.R. Holes can be constructed by conventional solution mining or leaching by continuously pumping fresh water or sea water into the cavity through a cased drill hole and withdrawing the salt in a brine solution.

Witnesses testified that it would not be necessary to dig the large holes required for maximum decoupling (300 to 1). Smaller holes, comparatively, could reduce the seismic signal to a level which would be difficult if not impossible to detect. For example, Dr. Albert Latter testified that a decoupling factor of 30 could be obtained in a hole one-thirtieth of the optimum volume. Dr. Bethe disagreed and contended that a decoupling factor of 30 would require a hole one-tenth of the optimum volume for maximum decoupling. Since the optimum hole volume is 91,000 cubic yards per kiloton at a depth of about 3,000 feet, a decoupling of a factor of 30 would require excavation of about 3,000 cubic yards, according to Latter, or about 9,000 cubic yards according to Dr. Bethe for a 1 kiloton explosion.

The diameter of holes required to provide decoupling factors of 30 and 300 were calculated by Dr. Albert Latter and are presented in the following table for each of several sizes of explosions.

| Nuclear yield (kilotons) | Diameter of hole to decouple by 300 in salt (or 50 in tuff) | Diameter of hole to decouple by 30 in salt (possibly 5 in tuff) |
|---|---|---|
| | *Feet* | *Feet* |
| 10 | 360 | 115 |
| 20 | 450 | 145 |
| 50 | 610 | 195 |
| 100 | 770 | 250 |
| 300 | 1,100 | 360 |

NOTE.—The apparent yield as measured on distant seismographs is the nuclear yield divided by the decoupling factor. E.g., a 100 kilotons explosion in a 250-foot-diameter hole in salt would have an apparent yield of about 3 kilotons.

Testimony indicated that nuclear explosions might also be concealed by firing them at such a time that the resulting seismic signals would be masked by the signals from large earthquakes. Theories of other possible techniques to prevent accurate location or to destroy the usefulness of the first motion criterion for identification were discussed. However, these possibilities were not considered as significant as concealment by decoupling.

### IMPROVEMENT IN GENEVA EXPERTS SYSTEM

The improvements recommended by the Berkner Panel listed above under "Detection and Identification of Underground Nuclear Tests" were expected to restore the capability of the EXPERTS system to that estimated in 1958, which was based on a 21-station installation in the Soviet Union.

The committee heard several proposals for improving the detection and identification capability of the control system by increasing the number of seismograph stations.

The Rand Corp. study, presented by Dr. Richard Latter, indicated that increasing the number of control posts complete with 100-element arrays, to 30 stations within the U.S.S.R. would leave about 9 unidentified earthquakes within the U.S.S.R. per year above magnitude 4.75 (20 kilotons under Rainier coupling conditions). About 36 unidentified events per year within the U.S.S.R. would remain unidentified above magnitude 4.35 (about 5 kilotons, Rainier coupling).

Dr. Roberts of the Carnegie Institute proposed a system of about 125 unmanned stations in the Soviet Union, spaced at 250-mile intervals, for detecting tamped explosions as small as 10 tons or decoupled explosions of about 3 kilotons. However, he pointed out that there would be no way of discriminating between these small explosions and earthquakes. He based his recommendation on his experience with 1 ton high explosive charges fired in water and on additional experiments with quarry blasts.

On this basis he estimated that 10 tons fired in rock could be detected at 250 miles under favorable circumstances, particularly if small arrays of seismographs were used at each station.

Dr. Bethe proposed in his testimony before the committee on April 20, 1960, a network of about 600 unmanned seismograph stations in the U.S.S.R., at intervals of about 125 miles. This network was designed to identify a high proportion of the earthquakes equivalent in size to a 20 kiloton fully decoupled explosion (about 70 tons closely tamped).

He estimated there would be 5,000 seismic events of this magnitude in the U.S.S.R., of which about 500 would be unidentified. Dr. Bethe further stated that since we are interested only in decoupled explosions we would have to inspect only that part of the 500 unidentified events which were located in salt dome areas. Hopefully, he reported this might involve as few as 5 events per year, since he estimates that only 1 percent of the 500 unidentified events would occur in salt dome areas of the U.S.S.R. This estimate is based on Dr. Bethe's assumption that 20 kiloton decoupled explosions could most easily be conducted in salt beds.

In a communication to the committee dated April 27, 7 days later, Dr. Bethe offered a revised statement which is printed in the appendix to the hearings. In this later statement he indicated that it would be possible, according to his new calculations, to reduce the 600 unmanned stations to 200 unmanned stations.

## ENGINEERING STUDY OF LARGE ARRAYS IN U.S.S.R.

An engineering study of the feasibility of installing large arrays of seismometers at 22 locations in the U.S.S.R. was presented to the committee.[5] This study revealed that the maximum number of seismometers which on the average can be used in an array is more like 30 than 100. This conclusion results from the practical problems of successfully finding a large number of quiet seismic locations within the 2-mile-diameter circle determined to be optimum for a large array.

[5] This study was made by United Electrodynamics Corp. for the Air Force Technical Applications Center, Apr. 15, 1960.

Thus, it is possible to achieve in a "realistic" array installation of about 30 seismometers an improvement in signal-to-noise level of a factor of 4 rather than the theoretical estimate of a factor of 10 for a 100-element "ideal" array.

The study further indicated that of the 22 control post locations spaced as recommended by the 1958 Conference of Experts, 16 stations can be located on good geology with 6 on fair, poor, or very poor geology. Thus, 6 of the 22 stations of an actual Geneva system of seismic arrays in the U.S.S.R. can be expected to have a capability lower than that theoretically expected by the EXPERTS.[6]

The report outlines the practical problems of engineering and logistics for stations from the Arctic areas to the deserts and high mountains of the southern part of the U.S.S.R. The project is compared in engineering difficulty to the multibillion-dollar DEW line project and is roughly estimated to cost $1 to $5 billion just for control posts in the Soviet Union alone.

### ON-SITE INSPECTION

The 1958 Conference of Experts recognized the difficulty of identifying a carefully concealed underground nuclear explosion. In the EXPERTS' report they stated:

> When the control posts detect an event which cannot be identified by the international control organ and which could be suspected of being a nuclear explosion, the international control organ can send an inspection group to the site of this event in order to determine whether a nuclear explosion has taken place or not.

How many annual on-site inspections would be necessary or permitted in the U.S.S.R. has been the subject of continuous controversy between the U.S.S.R. and U.S.-U.K. negotiations at Geneva. The U.S. February 11, 1960, proposal discussed above under "Detection and Identification of Underground Nuclear Tests" was an attempt to overcome the Soviet refusal to agree to inspection rights on all suspicious events by setting a specific number of annual inspections as a quota with a direct relationship to the technical requirement.[7] The hearings discussed the methods by which on-site inspections would be made. Inspection would consist of aerial overflight of an area of 40 to 200 square miles, subsequent ground survey of suspicious smaller areas located from the air, and, finally, actual drilling operations to locate radioactivity at the point deep underground where the explosion may have occurred.

In the first phase, aircraft equipped with conventional and infrared photographic equipment, and airborne magnetometers, would search for unusual vehicular traffic, mining or drilling activities, communication or powerlines, craters, rock slides, cracks in the earth, disrupted vegetation, etc.

In the second phase, ground examinations of selected smaller surface areas would utilize scientific equipment such as sensitive magnetometers, electromagnetic metal detectors, refraction shooting equipment,

[6] It is noted that problems of rapid and secure communication of signals and information both within and external to the test detection system were not covered to any extent during the hearings because of limitations in time.

[7] The Soviets have consistently held that agreement on the quota should be settled as a political question independently of the problem of the number of unidentified events.

etc. The objective would be to attempt to locate, hopefully within a circle of about 500 feet in diameter, the spot directly over the suspected underground nuclear explosion. Magnetometers and induction detectors may locate remnants of cable, drill tips, or drill casing, or other construction material which may have been used in preparing for the shot. Reflection and refraction shooting may be useful in locating underground cavities. Surface inspection on foot or horseback would be required to look for unusual signs of human activities connected with preparations for the test.

The third and final phase of inspection would be drilling. This phase would not be started until the successful conclusion of the second phase. By successful conclusion is meant that one or more areas equivalent to a circle of the order of 500 feet radius can be selected for drilling operations. Drilling operations must then be conducted in each one of these localized areas. The probability of success in such operations is given in the following table presented by Dr. Gerald Johnson, Lawrence Radiation Laboratory, Livermore:

*Probability of discovery of radioactive zone from tamped explosions within a 500-foot circle*

| Yield (kilotons) | 5 holes | 10 holes |
|---|---|---|
| | *Percent* | *Percent* |
| 1.7 | 3 | 12 |
| 20 | 26 | 94 |
| 100 | 100 | 100 |

It was variously estimated by scientific witnesses that the overall probability of success of an on-site inspection in locating and identifying a single underground nuclear explosion vares from "very nearly zero" to a probability of 100 percent success if the inspection were conducted in an exhaustive manner for a period of several years at a cost of tens of millions of dollars.

## DETECTION AND IDENTIFICATION OF NUCLEAR EXPLOSIONS AT HIGH ALTITUDE AND IN SPACE

The problem of detecting nuclear explosions at high altitudes and in space may be solved by detection equipment mounted on the surface of the earth in conjunction with detection equipment based in satellites in prescribed orbits around the earth or the sun. Techniques suggested by Technical Working Group I (July 1959) for installation at control posts of the EXPERTS system are tabulated below:

| *Method* | *Approximate theoretical range (miles) for 1 to 10 kilotons* |
|---|---|
| Direct optical | 300, 000 |
| Fluorescence | 500, 000 |
| Backscatter radar | 3, 000 |
| Cosmic noise absorption | 1,000 to 10,000 |
| Electromagnetic pulse | 3, 000 |

Techniques for employment on earth or solar satellites are listed in the following table:

| *Method* | *Approximate theoretical range (miles)* |
|---|---|
| Thermal X-rays | 200, 000, 000 |
| Prompt gamma rays | 300, 000 |
| Delayed gamma rays | 300, 000 |
| Prompt neutrons | 100, 000 |
| Delayed neutrons | 10, 000 |
| Trapped electrons | 30, 000 |

Ground techniques appear to have possibilities for detection out to ranges of 300,000 to 500,000 miles. Five of the six suggested satellite techniques are similarly limited to ranges of up to 300,000 miles from the satellite. At distances beyond 300,000 miles from an earth satellite system, slightly more than the distance to the moon, it is significant to note that only the X-ray technique will record radiation from a nuclear explosion. Thus, in more than 99.99 percent of space available for nuclear tests by a violator only the X-ray technique has the necessary detection range. Furthermore, this X-ray technique is subject to degradation in range by the technique of shielding by a potential violator to reduce the intensity of X-rays from the explosion. It is estimated that the above range for an unshielded explosion would be reduced by a factor of 10 or more for explosions in the megaton yield range and by a factor of 100 or more for explosions of the order of 10 kilotons in yield by shielding.

Very little is known about the natural radiation of gamma rays, neutrons, and X-rays in regions where satellites would be installed. The effectiveness and reliability of the satellite system will therefore depend greatly upon the degree to which pulses of radiation similar to those produced by nuclear explosions in space might be produced naturally.

### SIGNIFICANCE OF FURTHER WEAPON DEVELOPMENTS THROUGH CLANDESTINE TESTS

As previously discussed, the witnesses agreed that the 180-station Geneva system would not have a capability of detecting and identifying seismic events below 20 kilotons equivalent as originally thought. All witnesses also agreed that seismic signals from underground tests could be reduced by decoupling up to a factor of 300. Accordingly, with the present state of knowledge, detection of an underground low-yield test by a violator attempting to conceal it will be extremely difficult if not impossible. Similarly, it was agreed that clandestine testing of high-yield weapons in space could be conducted within the present scope of missile and satellite technology.

In view of this, the question naturally arises as to the importance or significance of clandestine tests. In the opinion of the scientists, who testified at these hearings, further underground tests at yields smaller than 20 kilotons would permit development of new weapons in the low kiloton range. They also agreed that further testing in space would permit full-scale tests of weapons developed by underground scaled-down tests, as well as permit development of improved models of high-yield nuclear weapons.

The witnesses differed, however, on the relative military significance of such developments compared to the stockpiles of sophisticated

weapons presently available to the three principal nuclear powers, the United States, the United Kingdom, and the U.S.S.R. For example, Dr. Teller considers such developments of very great importance, while Dr. Bethe considers they would be of only nominal importance.

The importance to the United States of future development of low-yield nuclear weapons, as well as improvements in high-yield weapons, is determined by military requirements—strategic and tactical. These are the responsibility of various agencies in the executive branch, including the Office of the President, the Department of Defense, and the AEC, as well as designated congressional committees in the legislative branch. However, the military significance to the United States of possible future nuclear weapons must also be considered and assessed in relationship to the overall diplomatic and foreign policies of the United States. While these hearings were concerned primarily with the technical problems of a nuclear test ban, it is recognized that diplomatic and policy matters of great importance must also be considered in the final evaluation. The latter, however, were not within the scope of these hearings.

## RESEARCH AND DEVELOPMENT REQUIRED FOR SEISMIC IMPROVEMENT

It was the unanimous opinion of all witnesses that a vigorous and sustained program of research and development is necessary to improve our instrumentation and our techniques of detection, identification, and inspection of nuclear explosion tests.

The Berkner Panel proposed a comprehensive research program in seismology and recommended a systems development program directed toward the specification of equipment required for a worldwide seismic system for monitoring underground nuclear explosions. The March 1959 Berkner report recommended a total expenditure of $22.8 million for the first year and $30 million for the second year. A U.S. research and development program designated Project Vela Uniform, was assigned to the Department of Defense's Advanced Research Projects Agency (ARPA) in September 1959. The Advanced Research Projects Agency authorized implementation of the program in February 1960 by the Air Force Technical Applications Center (AFTAC).

This program was allocated $8.5 million in December 1959, of which $5 million was obligated by April 19, 1960. Testimony indicated that there is no line item in the fiscal 1961 Department of Defense budget for this program and future funds thus would have to be obtained from other Department of Defense projects.

Under Project Vela Uniform, AFTAC has undertaken the following major tasks:

(*a*) Equip a large number of world seismological observatories with standard calibrated seismographs and auxiliary equipment and provide for the free exchange of data accumulated throughout the continuous operation of such equipment. This program is designed to provide uniform and quantitative seismic data in support of research on the nature of earthquakes and the characteristics of seismic waves produced by them. A special panel established by the National Academy of Sciences will provide recommendations on equipment specifications and on deployment and use of this equipment. Pro-

curement, installation, and distribution is to be handled by the U.S. Coast and Geodetic Survey of the Department of Commerce with the first 50 sets of equipment expected to be available in mid-1960.

(*b*) Stimulate basic research in seismology through the establishment of programs at universities and other research organizations to include investigations on the generation and propagation of seismic waves, studies of the structure of the earth, and the development of new types of seismic instruments. These efforts are expected to contribute to the solution of detection problem and to result in a significant increase in the number of trained scientists who would be required for the technical operations of a control system.

(*c*) Carry out a systems development program to include the construction and operation of a Geneva-type station recommended by the 1958 Conference of Experts and the design and operation of a systems development laboratory and seismograph station based on Berkner Panel recommendations. Characteristics of the latter station will be continually modified in the light of technical advances.

(*d*) Investigate the magnitude and characteristics of seismic effects from both underground nuclear and high explosive detonations for the purpose of obtaining data on the difference in signals generated, the effects of depth of burial and geology and to obtain possible additional criteria for differentiating between natural and artificial seismic events. Extensive measurements to be made at distances from a few feet out to distances as far as 2,000 to 3,000 miles from these explosions would provide data which are expected to result in major improvements in detection capabilities. (Nuclear explosions were considered essential by most of the witnesses for a research program of this nature.)

### RESEARCH AND DEVELOPMENT REQUIRED TO DETERMINE FEASIBILITY OF DETECTING NUCLEAR EXPLOSIONS IN SPACE

The March 1959 report of the Panofsky Panel [8] proposed a program of research and development to determine the feasibility of systems for detecting nuclear explosions in space. The U.S. Government is considering a major program of research and development based on the recommendations of this report. This program, designated Vela Sierra (ground-based techniques) and Vela Hotel (satellite-based techniques), is the responsibility of the Advanced Research Projects Agency (ARPA).

Scientific opinion at the hearings unanimously supported the requirement for an intensive program of research and development to determine the feasibility of detecting nuclear explosions in space. A program of research and development was presented by ARPA which amounts to the threefold task of (1) surveying the background levels of radiation in space to be encountered by satellite detectors; (2) developing adequate detection equipment for satellites, launching, tracking, and data reduction systems; and (3) developing equipment for detection of nuclear explosions in space from control posts of the 1958 Geneva EXPERTS system.

[8] The Panel on High Altitude Detection under the chairmanship of Dr. Wolfgang Panofsky was appointed by the Special Assistant to the President for Science and Technology and on Mar. 16, 1959, submitted its final report.

The program contemplates utilizing the facilities of the Department of Defense, the Atomic Energy Commission, and the National Aeronautics and Space Administration in the most effective way possible to accomplish the program in the shortest possible time. It is estimated that a program of 3 to 5 years of research and development will be required to determine the feasibility of a system for detecting nuclear explosions in space.

ARPA has requested $20 million for fiscal year 1961 to pursue the program of research on surface and satellite techniques for detecting high-altitude explosions.

## CHAPTER III. DETECTION AND IDENTIFICATION OF UNDERGROUND NUCLEAR TESTS

### GENEVA SYSTEM

The Conference of Experts, convened in Geneva during July and August of 1958, recommended a control system of 180 stations for detecting violations of a possible agreement on the suspension of nuclear tests. In their studies the 1958 Conference of Experts considered and evaluated the methods of recording acoustic, hydroacoustic, electromagnetic, and seismic signals, and the collection of radioactive debris from the atmosphere for the detection and identification of nuclear explosions. Consideration was also given to methods of detecting and identifying nuclear explosions at high altitude or in space, but the Conference did not include these methods in the recommended system.

The report of the 1958 Conference of Experts concluded that the recommended system would have a good probability of detecting and identifying nuclear explosions of 1 kiloton or more in the atmosphere up to an altitude of about 6 miles and a good probability of detecting but not always identifying nuclear explosions taking place at altitudes from 6 to about 30 miles. This capability was based principally on the acoustic, electromagnetic, and radioactive debris techniques for detection of nuclear explosions in the atmosphere supplemented by on-site inspection for nuclear explosions on the surface.

The EXPERTS considered that there would be a good probability of detecting by hydroacoustic, and seismic methods nuclear explosions down to 1 kiloton detonated deep in the oceans.

Considerations of detecting nuclear detonations in space were also based on estimates for the detection of unshielded 1 kiloton detonations by the gamma and neutron methods. Detection distances were estimated up to hundreds of thousands of miles but the actual ranges of distances were known to be limited by radiation backgrounds in space about which little was known at the time.

In their consideration of underground nuclear explosions the EXPERTS agreed such nuclear explosions could be detected with a good probability down to 1 kiloton equivalent yield (Rainier coupling) but could not be identified by the seismic recordings. In estimating the seismic detection capability, explosions and earthquake signals were normalized or related to a single U.S. underground nuclear explosion, Rainier, detonated in September 1957. This was the only deep underground nuclear test explosion conducted by the United States prior to Conference of Experts.[1] It was recognized that conditions of coupling might be greater or less than "Rainier Coupling." At that time no clear understanding existed of the various factors involved. Therefore this subject did not receive extensive consideration.

[1] The U.S.S.R. representatives at the 1958 Conference of Experts did not offer any data on underground nuclear explosions. In 1959, during the meetings of Technical Working Group II, the Soviet representatives stated that the U.S.S.R. had conducted no underground nuclear explosions.

The 1958 Conference of Experts concluded that with the recommended network of 180 control posts, underground nuclear explosions under conditions of Rainier coupling could be detected down to 1 kiloton during periods of favorable noise conditions and down to 5 kilotons during periods of unfavorable noise conditions.

The Conference concluded that the network of control posts would be unable to distinguish the signals from underground explosions from those of some earthquakes; however, the Conference further concluded that the system could identify as being of natural origin about 90 percent of the continental earthquakes whose signals are equivalent to 5 kilotons or larger. Below 5 kilotons capability for identification falls off very rapidly and it was concluded that between 1 and 5 kilotons only a few percent of the earthquakes could be identified as of natural origin.

It was agreed that about 2,000 earthquakes of magnitude equivalent to or greater than 5 kilotons occurred each year on the continents of the world. On this basis, the United States calculated that there would be 100 continental events annually above 5 kilotons equivalent which would be unidentified. Soviet experts estimated that there would be annually only 20 unidentified events on continents. Thus the final report of the EXPERTS presented the conclusion that with the Geneva system there would be 20 to 100 unidentified events on continents annually.

The 1958 Conference of Experts agreed that the most promising technique available for the identification of earthquakes by seismic means was the criterion of first motion. The possibility of using the first motion of the seismic signal to identify earthquakes arises from the fact that seismologists have observed that the first motion recorded on a seismograph from an earthquake will in some cases be outward from the source and in other cases will be inward toward the source depending upon the azimuthal distribution of the seismographs around the earthquake. First motion in the case of an underground explosion will in all cases be outward from the source of the explosion. Unfortunately, some earthquakes have been observed to produce outward motion in all azimuths surrounding the source, therefore, the first motion criterion will not identify underground explosions but can identify earthquakes with good reliability. In order to identify the direction of first motion of a seismic signal however, it is necessary that the amplitude of that signal be sufficiently large so that its first motion will be clearly discernable above the background noise level.

The number of continental earthquakes per year between 1 kiloton and 5 kiloton equivalent or larger was estimated to be about 3,000 with only a few percent of this number identifiable by the first motion criterion. This left a thousand or more seismic events of between 1 and 5 kiloton equivalent (Rainier coupling) and about 100 seismic events of 5 kilotons equivalent or more (Rainier coupling) which could be suspected of being nuclear explosions.

The 1958 Conference of Experts discussed in some detail the problem of conducting on-site inspections. Calculations were made of the accuracy of location which the seismic data could establish. Methods of measuring resultant heat and radioactivity from an underground nuclear explosion, and other phenomena which might be applicable were considered. Although the EXPERTS' report contains the statement that onsite inspection would always provide some probability of

locating an underground nuclear explosion, the 1958 Conference of Experts did not attempt to arrive at any estimate of that probability.

### THE EFFECTS OF HARDTACK II DATA

Subsequent to the 1958 Geneva Conference of Experts, the United States conducted a series of underground explosions in Operation Hardtack II during the fall of 1958. Data recorded at both conventional observatories and special seismic stations, established for this program, provided firm evidence that the 1958 Conference of Experts was too optimistic in its estimates of the capabilities of the recommended control system. Experimental data obtained by these tests revealed that the amplitude of seismic signals, including the amplitude of first motion, was smaller than that estimated on the basis of the Rainier data.[3]

As a result of these new data, it has now been firmly established that the direction of first motion cannot be reliably identified down to 5 kiloton equivalent at the distances agreed by the 1958 Conference of Experts but would be reliable for this purpose only at substantially higher yields or at smaller distances. Furthermore, based on these new data, estimates of the numbers of earthquakes throughout the world which would provide seismic signals equivalent to a specific nuclear yield were considerably increased. Based on the Hardtack II data, it is estimated that of the total annual number of continental earthquakes, about 1,000 will be equivalent to 20 kilotons or more, about 2,500 will be equivalent to 5 kilotons or more, and about 7,500 equivalent to 1 kiloton or more. As a result of these estimates the annual number of unidentifiable continental earthquakes equivalent to 5 kilotons or larger was found to be greater than that previously estimated by the 1958 Conference of Experts (20 to 100) by a factor of 10 or more.

In addition to the above reevaluation of the capabilities of the control system, recommended by the EXPERTS, a further reduction in its capability obtains when nuclear explosions are conducted in sufficiently large holes located deep underground. Extensive theoretical calculations combined with measurements on the Rainier test and further substantiated by the more recent measurements involving chemical explosions in the Cowboy Series of tests indicates that the seismic signal produced by an explosion in such a hole in salt or hard rock could be reduced by a factor up to 300 relative to the seismic signal from such an explosion conducted in Nevada tuff. This phenomenon, called decoupling, is discussed more fully in chapter IV.

### BERKNER PANEL IMPROVEMENTS

As a result of the Hardtack II data the capability of the EXPERTS' system was reevaluated. In considering methods of restoring the originally estimated capability, the Berkner Panel recommended the following improvements:

(*a*) Increasing the number of seismometers in the array at each control post from 10 recommended by the EXPERTS to 100 in order to improve the signal-to-noise ratio.

[3] The seismic instrumentation for the Hardtack II underground nuclear explosions was considerably more extensive than that for the Rainier event.

(*b*) The use of long period seismographs at all control posts instead of at "certain control posts" as recommended by the EXPERTS to aid in the identification of earthquakes.

(*c*) The use of seismometers in holes sufficiently deep (5,000 feet) to avoid surface microseismic noise, and

(*d*) The addition of unmanned stations to the network recommended by the EXPERTS at spacings of 100 miles throughout the continental land masses of the earth to greatly increase the capability of the control system to distinguish between earthquakes and nuclear explosions.

In addition to the above the Berkner Panel recommended that a vigorous and comprehensive research and development program would result in important improvements in the ability to identify earthquakes of small magnitude.

### CAPABILITIES AND LIMITATIONS

The United States Delegation to the Technical Working Group II which met in November and December 1959, recommended improved seismic instrumentation to be employed at control posts and criteria for the identification of earthquakes in the light of the new Hardtack II data. However, no attempt was made to evaluate the capability of the control system recommended by the 1958 Geneva Conference of Experts which could result from the incorporation of these recommendations. An estimate of the capability of the control system was made by AFTAC in January 1960 based upon the Technical Working Group II criteria. This estimate is based upon the ability of the control posts in the United States, U.S.S.R., and the United Kingdom only to identify earthquakes in the U.S.S.R. The results are shown in the following table:

*Estimated number of earthquakes in the U.S.S.R. detected but unidentified by control posts in the U.S.S.R., United States, and United Kingdom*

| Number | Magnitude | Equivalent yield (kilotons) | Number of unidentified earthquakes | |
|---|---|---|---|---|
| | | | 100 detector array | 10 detector array |
| 620 earthquakes | 4.0 | 2 | 560 | 590 |
| 320 earthquakes | 4.3 | 4 | 260 | 290 |
| 170 earthquakes | 4.6 | 11 | 110 | 140 |
| 123 earthquakes | 4.75 | 19 | 70 | 100 |
| 72 earthquakes | 5.0 | 40 | 35 | 45 |
| 47 earthquakes | 5.2 | 80 | 20 | 24 |

A more recent report by the Rand Corporation presents such an evaluation using the criterion of Technical Working Group II and also a new criterion believed to be adequately confirmed by the Hardtack II data. This analysis of the EXPERTS' system capability was directed toward the question of how many earthquakes per year of magnitude greater than 4.75 (the threshold proposed by the United States on February 11, 1960, at Geneva) would fail to be identified as earthquakes by the EXPERTS control system and could therefore be suspected of being nuclear explosions. For a system of Geneva-

type control posts, equipped with the improved seismic instrumentation recommended by the Berkner Panel, stations were located in each of the three countries as follows: 11 in the United States, 1 in the United Kingdom, and 21 in the Soviet Union.[3] The Rand study indicated that there would be about 53 unidentified seismic events per year in the Soviet Union above the magnitude 4.75. For the complete Geneva system of 180 control posts installed throughout the world as recommended by the 1958 Conference of Experts, the number of annually unidentified seismic events in the Soviet Union would be reduced to about 28.

The Rand Corporation then reviewed the basic assumptions upon which the Technical Working Group II criterion were based. It was found that new, less rigorous criteria for identification could be employed if seismic signals only in the distance range out to 700 miles from each stations were used. Within this distance the seismic data were found to be much more reliable than in the ranges from 1,100 to 2,200 miles which were included as a basis for the Technical Working Group II criterion. For example, it was found that first motion could be read easily out to distances of 400 miles if the peak signal was 10 times the background noise and at distances between 400 and 600 miles if the first motion is 20 times the background noise instead of the factors of 20 to 40 used in the Technical Working Group II criteria. On this basis it was further found that, because of the greater reliability of the seismic data within 600 miles of the stations, it is possible to reliably identify earthquakes on the basis of only two stations recording clear rarefactions rather than the requirement of Technical Working Group II for four rarefactions.

With this new criterion the Rand Corporation reevaluated the capabilities of the 1958 Geneva Experts system and found that it was substantially the same as the results which were obtained from using the Technical Working Group II capabilities.

The Rand Corporation next considered possible improvements to the 1958 Geneva Experts system by adding stations and evaluating the capabilities on the basis of the new, less rigorous criterion. The results of this study are shown in the following table:

*Effect on the 1958 Geneva Conference system by adding stations in the Soviet Union*

| Number of stations in the Soviet Union: | *Number of unidentified seismic events (greater than 4.75 magnitude)* |
|---|---|
| 21 | 53 |
| 25 | 20 |
| 30 | 9 |

The Rand study indicated that very significant improvements in identification could be achieved by increasing the number of stations within the U.S.S.R. from 20 to 30. Beyond that number, many additional stations would be required to achieve relatively small improvements.

[3] The numbers of control stations were prorated to each of the three countries on the basis of the EXPERTS station spacing and the respective land areas concerned.

COST OF GENEVA CONTROL SYSTEM IN DOLLARS AND MANPOWER

The basic organizational concept of the International Control System proposed by the 1958 Geneva Conference of Experts envisions three major echelons: The International Control System Headquarters, the Regional Control Offices, and the individual Control Stations.

The International Control System Headquarters would be organized so as to provide the following services: Data analysis and research, radiochemical analysis, communications, weather information, an operations center, and a central inspection agency.

Regional offices strategically located with respect to the individual control posts would be charged with providing the required administrative and logistical support to those posts within their respective areas.

Of the total of 180 control posts proposed by the EXPERTS, 170 posts would be located on land while 10 would be aboard ships deployed throughout the world in accordance with the spacing requirements prescribed by the Conference of Experts.

Manpower requirements for the International Control System Headquarters is estimated at from 1,500 to 2,000 personnel, most of whom would provide those technical services indicated. The total manpower requirement for establishing and operating the entire system was estimated at 20,000 people.

Between 30 and 35 technicians would be required at each individual control post together with varying numbers of additional support personnel depending upon the location of the individual post. This number does not include personnel for operation of ground-based techniques for detection of nuclear explosions at high altitude or in space.

The cost of establishing the International Control System proposed by the Conference of Experts and additional ground techniques for detection of nuclear explosions in space but excluding any satellite detection systems was estimated at approximately $1 billion with an annual operating cost of approximately $250 million per year.

Reliable and detailed estimates of the cost of an International Control System are most difficult at this time because of two principal factors:

(*a*) The absence of agreement at Geneva as to the actual number and deployment of control posts.

(*b*) The present uncertainty as to type of detection equipment and techniques which might eventually be adopted for employment at the control posts.

It must be emphasized that the $1 billion figure for initial establishment of an international system and the $250 million annual operating cost does not include the establishment and operation of a satellite detection system for nuclear tests in space as considered by Technical Working Group I. Testimony on estimated costs and requirements for space-based detection systems was very general. Witnesses indicated that very little is known at the present time about problems that will be encountered by satellite-based detectors including the ability of the instruments to discriminate between signals produced by a nuclear detonation in space and those from natural sources.

## CHAPTER IV. MEANS OF CONCEALING UNDERGROUND NUCLEAR TESTS

A nuclear explosion conducted in a hole only large enough to accommodate the device exerts such tremendous pressure on the adjacent rock that this material is stressed far beyond its breaking strength, resulting in large motion of the surrounding earth outward from the explosion. This earth motion gives rise to strong seismic waves which may be transmitted to considerable distances from the explosion. An explosion conducted under such conditions is called a tamped explosion. (Rainier and Hardtack II nuclear tests were all tamped in a rock called Nevada tuff.)

### DECOUPLING

Dr. Albert Latter devised a method of conducting explosions in underground cavities in such a manner that theoretically the size of the seismic signal transmitted to the surrounding medium is smaller by a factor of 300 than the signals from the same explosion conducted in Nevada tuff under good tamping conditions, if the hole is in hard rock like granite or in salt. If the hole is in Nevada tuff the signal will be reduced only by a factor of 50.

This theory of "decoupling" nuclear explosions is based upon some complicated mathematics but the physical concept of the idea can be explained fairly simply. By exploding a nuclear device in a large hole underground, the pressure produced by the explosion upon the walls of the cavity can be greatly reduced. The larger the hole in relation to the yield of the weapon, the lower the pressure on the walls. By placing the hole deep underground the external pressure due to the overlying material (overburden) will increase in proportion to the depth. It was found that by a suitable choice of hole diameter and depth that the internal pressure of the explosion could be counterbalanced by the external pressure from the overburden. As a result the cavity responds elastically, i.e., expands in volume slightly at the instant of the explosion but returns to its original dimensions in a matter of seconds. Under these conditions of elastic performance of the hole, Dr. Albert Latter calculated that an underground nuclear explosion by optimum decoupling could be made to appear 300 times smaller in yield on distant seismographs than a nuclear explosion of the same size tamped in Nevada tuff. For example, by fully decoupling a 300-kiloton nuclear explosion in a hole in salt or hard rock, it could be made to appear no larger than a 1-kiloton explosion tamped in Nevada tuff. Furthermore, the shape of the hole does not need to be spherical. For instance the decoupling factor is not greatly affected if the cavity has a football shape where the long axis is 2 to 3 times larger than the short axis.

The theory predicts that at depths below the surface of about 3,000 feet, the optimum volume for decoupling in hard rock or salt is 91,000

cubic yards per kiloton. The optimum hole size as a function of yield is given in the following table.

| Yield (kilotons): | *Hole diameter (feet)* |
|---|---|
| 1 | 170 |
| 10 | 360 |
| 20 | 450 |
| 50 | 610 |
| 100 | 770 |
| 300 | 1,100 |

The mathematical analysis of this problem leads to the conclusion that for an explosion of given size there is an optimum volume of the hole where maximum decoupling is achieved and beyond which an increase in volume will not cause a further reduction in the strength of the seismic signal. The theory by itself however does not predict whether there is or is not a gradual decrease in the strength of the seismic signal as the hole increases from a very small volume up to the optimum size.

### EXPERIMENTAL DECOUPLING (COWBOY)

Experiments were conducted by the Atomic Energy Commission in early 1960 to test the theory of decoupling and to determine how the decoupling factor would be reduced if the volume of the hole was less than the optimum volume. These tests were conducted in a salt dome with conventional explosive charges ranging from 20 to 2,000 pounds. Spherical cavities of 12- and 30-foot diameters were constructed at a depth of 800 feet. The seismic signals produced by the cavity explosions could be compared directly with signals from closely tamped explosions of the same yield in the same medium and at the same depth. The seismic signal measurements were made at 11 locations, some as far out as 60 miles. Measurements were taken both on the surface and underground.

The experiments completely verified the theory of decoupling. They showed that the seismic signal from a fully tamped explosion was about 120 times bigger than the signal from a decoupled explosion of the same yield. The figure of 120 differs from the decoupling factor of 300 because the Cowboy experiment compared signals from tamped explosions in salt with signals from decoupled explosions in salt whereas the figure of 300 compared the signal from a fully tamped explosion in Nevada tuff to the signal from a similar explosion in a large hole in salt. The ratio of 300 to 120, namely 2.5 is the amount of decoupling achieved merely by change in media from Nevada tuff to salt.

The experiment produced the surprising result that it is possible to attain a smaller, but still large, decoupling factor if the volume is reduced well below the optimum volume. For a decoupling factor of 30, the volume could be reduced by a factor of about 30 (A. Latter) or 10 (H. Bethe). Thus, if a violator required only a factor of 30 decoupling rather than the maximum of 300 he could achieve this result with a hole of only $\frac{1}{10}$ to $\frac{1}{30}$ of the optimum volume.

While conventional rather than nuclear explosives were used in the experiments, it is expected that for two explosions, one nuclear and the other conventional, in the same size cavity, the conventional explosive will produce a higher pressure on the cavity wall than the

nuclear explosion. Thus nuclear explosions should decouple at least as much if not more than chemical explosions. Tests with nuclear explosives are needed to verify this conclusion and to provide precise data under conditions such as those in which concealment of a nuclear explosion might be attempted.

While the large hole has been shown to make a drastic reduction in the strength of the seismic signal, smaller but still important reductions might be achieved by increasing the depth of the explosion or by carrying out the explosions in other geological materials. These would require further full-scale tests. Additionally it may be theoretically possible to increase the decoupling factor by placing heat absorbing materials in the cavity thus decreasing the explosion pressures on the walls. Dr. Teller believes decoupling factors of 3,000 or more could be achieved by this method while Dr. Bethe is of the opinion that reducing the coupling by placing heat absorbers in the cavity will probably not work. Experiments would have to be conducted to determine the facts on this point.

### CONSTRUCTION OF LARGE UNDERGROUND CAVITIES

It was definitely established by the testimony that it is feasible to construct cavities in salt domes of the required depth, size, and shape to decouple nuclear explosions up to about 100 kilotons. Such cavities can most easily be constructed in salt domes by using solution mining techniques. There are 200 or more salt domes in the United States, mostly in the Gulf coast region although there are a few in Kansas and New York State. The Soviet Union is reported to have more than a hundred salt domes in a region of about the size of the Gulf coast area of the United States.

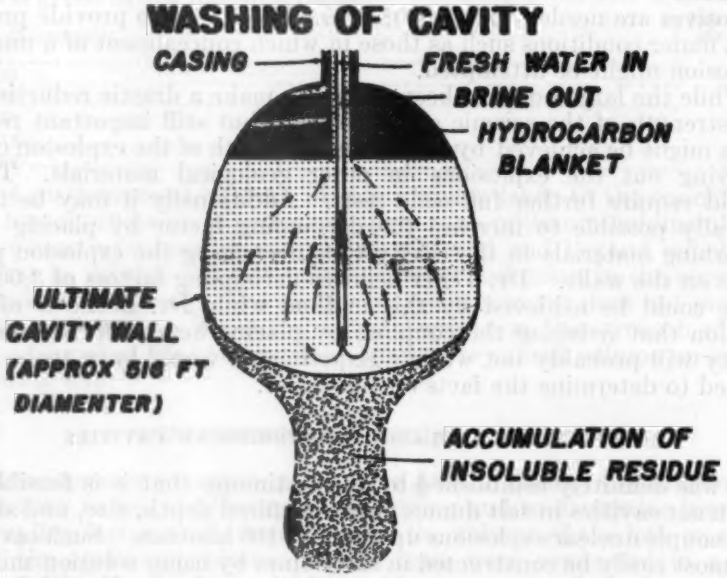
The salt domes in the United States range in diameter from one-half to 7 miles, averaging 1 to 2 miles. The average depth from the surface to the top of the domes is between 500 and 1,000 feet, while the average thickness of the salt is over 10,000 feet. About 250 underground cavities have been constructed in the United States alone for the storage of petroleum products. Probably 50 or more have also been constructed by salt and chemical companies for the production of brine. The cavities constructed for petroleum storage range in size from 5,000 to 200,000 cubic yards and larger cavities have been constructed for brine production.

The techniques for solution mining are matters of public record. Since numerous salt domes and oil fields exist in the Emba Region of the U.S.S.R. it is only prudent to assume that similar cavities are presently in existence in this area and elsewhere in the world.

Solution mining, or leaching, consists of continuously pumping fresh water into the cavity via a cased drill hole and withdrawing the salt in the form of brine. (See fig 1.) The size of the cavity can be increased by leaching over a long time or at a higher rate or both. The shape can be controlled by using a technique employing a hydrocarbon for controlling the cavity roof and by varying the point at which the fresh water is injected and the direction of circulation—top to bottom of the cavity or vice versa. Periodic sonic surveys are used to make sure the desired cavity shape is being attained.

55085—60——5

FIGURE 1




Construction costs have been estimated for a cavity of 2,700,000 cubic yards located at a depth of 2,500 feet in a salt dome. If spherical, the diameter of this cavity would be about 516 feet. Based on the decoupling study, this cavity would provide maximum decoupling for a 30 kiloton nuclear explosion. If only one drill hole is used, the time required to drill and case the well, wash the cavity and empty it of brine would be 48 months. The cost would be $2.5 million exclusive of the cost of the site, site preparation, fresh water supply, utilities, and brine disposal facilities. These costs are estimated to run from one-half to one million dollars depending on the site location and other factors. The several million dollars invested in the hydrocarbon blanket during construction would be recoverable.

If five holes are drilled for washing the cavity, the construction time would be 16 months and the cost would be slightly over $11 million exclusive again of site, site preparation, fresh water supply, utilities, and brine disposal facilities. The higher construction cost in this case is brought about mainly by the cost of drilling more holes and installing greater pumping facilities.

A cavity of 8.3 million cubic yards, and about 750 feet in diameter, sufficient to decouple a nuclear explosion of about 90 kilotons, could be constructed in about 28 months, by using five drill holes, at a cost estimated to be $13.5 million.

Collapse of cavities in salt domes is relatively rare. At depths of 2,500 to 3,250 feet, cavities located in salt are expected to have an initial closure of between 5 and 10 percent. The rate of closure is greatest at the beginning and decreases with time.

For concealment purposes, the brine pumped out of the cavity can be disposed of by injecting it into another formation already containing salt water. Brine produced in oil storage operations for example

in some cases is dumped into the ocean. Thus washing operations would not necessarily be detectable by salinity measurements in oceans or seas.

### OTHER POSSIBLE CONCEALMENT METHODS

A possible way aside from decoupling to hide an underground nuclear explosion, at least in the low yield category, is to set it off in a highly seismic area immediately following a fairly large earthquake in the area. In this way the initial characteristics of the seismic wave from the explosion would be lost in the strong earthquake signals. Even if the presence of the signal from the explosion were to be noticed, it is likely that the problem of defining the area of the source would be made very difficult.

It was also suggested that advantage could be taken of the first motion criteria for identifying earthquakes. A decoupled underground nuclear explosion could be preceded by a much smaller decoupled or undecoupled nuclear or chemical explosion whose first motion would be too small to be detected. However, its much higher second motion could be made to coincide with the small first wave from the second explosion. In this way the signal from the larger explosion might be made to look like that from an earthquake. Other theories to conceal and confuse a control system were discussed. The validity of these theories can only be determined by testing in which concealment or falsification is actually attempted.

## CHAPTER V. IMPROVEMENT OF SEISMIC DETECTION AND IDENTIFICATION

Following the analysis of the seismic data from the underground nuclear explosions of Operation Hardtack II, it was recognized that the capabilities of the control system proposed by the 1958 Geneva Conference of Experts was considerably less than the EXPERTS had concluded. At about the same time it was established theoretically that concealment could be accomplished by decoupling the seismic signals from an explosion. In recognition of these problems, the Panel on Seismic Improvement, under the chairmanship of Dr. Lloyd V. Berkner, was established in December 1958 to make recommendations on techniques for improving detection. The Berkner Panel in its report of March 1959 recommended several methods for improving the proposed control system which appeared to be within the existing state of technology. In addition, the Panel recommended a long-term research and development program for improving seismic detection. Of those techniques considered to be within the existing state of technology it appeared that two could be applied immediately to the control system recommended by the 1958 Conference of Experts.

The first of these techniques consisted of adding long-period seismographs to all of the control posts rather than installing them only "at certain posts" as recommended by the 1958 Conference of Experts.

The basis for this recommendation was the observation that those few stations in North America which were equipped with long-period seismographs detected waves from two of the Hardtack II explosions in Nevada (Blanca, 19 kilotons, and Logan, 5 kilotons) at distances of 2,000 miles or more. Although these waves were marginally recorded from the smaller shot, they appeared to differ somewhat in frequency content from waves recorded from earthquakes of similar magnitude. The Berkner Panel could not evaluate in detail the improvement to be expected from this technique but believed that further research and development would show that the analysis of long-period waves would be an important aid in identifying seismic disturbances.

The second technique considered to be immediately available was to increase the array of seismometers at the control posts from the "approximately 10 short-period seismometers" recommended by the 1958 Conference of Experts to approximately 100 seismometers. This recommendation was based on theoretical and experimental studies conducted by AFTAC. As the number of seismometers in an array is increased, signals from underground explosions and from earthquakes are more clearly revealed in the presence of background noise (micro tremors of the earth which are known to occur continuously at all locations).

Further work has been conducted on both of these techniques by Rand Corporation, Columbia University, and AFTAC. In particular, a method has been developed for improving the capability of the long-

period seismographs for detecting small signals. This is accomplished by the use of a filter (the so-called notch filter) which rejects frequencies corresponding to the largest noises in the seismic spectrum. This method therefore looks even more promising at the present time than it did at the time of the Berkner Panel deliberations.

Additional studies of large arrays have also been conducted which indicate that the predictions of the Berkner Panel on their effectiveness were theoretically correct but not completely achievable in practice. It has been learned for example, that finding acceptable sites for such large numbers of detectors will be very difficult and perhaps impossible in some areas, and that the maintenance of the many hundreds of miles of cable at such an installation is probably a serious drawback to the application of this technique. The effect of these practical considerations will probably be to limit the number of detectors at most stations, to numbers substantially below 100 (see chapter VI), and therefore prevent the full achievement of the predicted improvement.

Two additional techniques which the Berkner Panel felt to be potentially important although requiring further research, were the development of deep hole detectors and unmanned seismograph stations.

The deep hole detector method envisioned the installation of seismographs in drilled holes at depths of several thousand feet below the earth's surface. Such a detector installation is illustrated in figure 2. Theoretical considerations, as well as the limited number of measurements actually completed, suggest that the troublesome background noise which limits the detection of small signals will be considerably reduced at great depths. Thus, if a practical system can be developed based on this method, the control stations would be capable of detecting considerably smaller explosions and earthquake signals than is presently possible.

More recent work by AFTAC continues to show results which are favorable for this technique, although additional research will be required.

Unmanned stations were a subject of discussion during the hearings. Proponents of this method conceived of a system of several hundred seismic detection stations established within an area the size of the U.S.S.R. An example of a suggested network of unmanned stations is shown in figure 3. Each station would be equipped with perhaps one or two seismographs and would be connected by suitable radio or land line links to the manned stations of the control system. The detectors would therefore sense the motions of the earth at a number of locations which would be much closer to a source of a potentially suspicious disturbance than would be the control posts. The resulting signals would therefore be larger and would contain more information regarding the location and probable nature of the source.

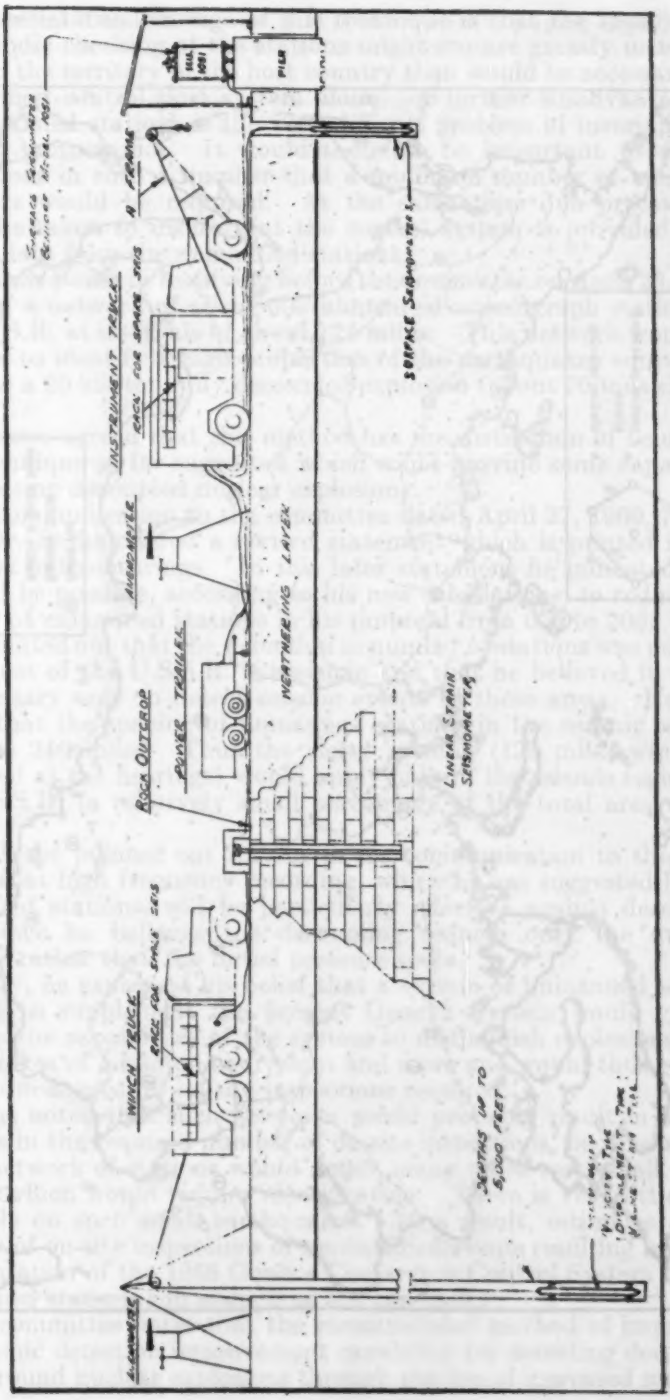

SURFACE SEISMOMETER
RECORDER NICOLET 1081
SEAL
1081
PILOT
A FRAME
INSTRUMENT TRUCK
BACK FOR SPARK SETS
SURFACE SEISMOMETER
AMMETER
WEATHERING LAYER
ROCK OUTCROP
POWER TRAILER
LINEAR STRAIN
SEISMOMETER
WINCH TRUCK
BACK FOR SPARK SETS
DEPTHS UP TO
5,000 FEET
AMMETER

FIGURE 2

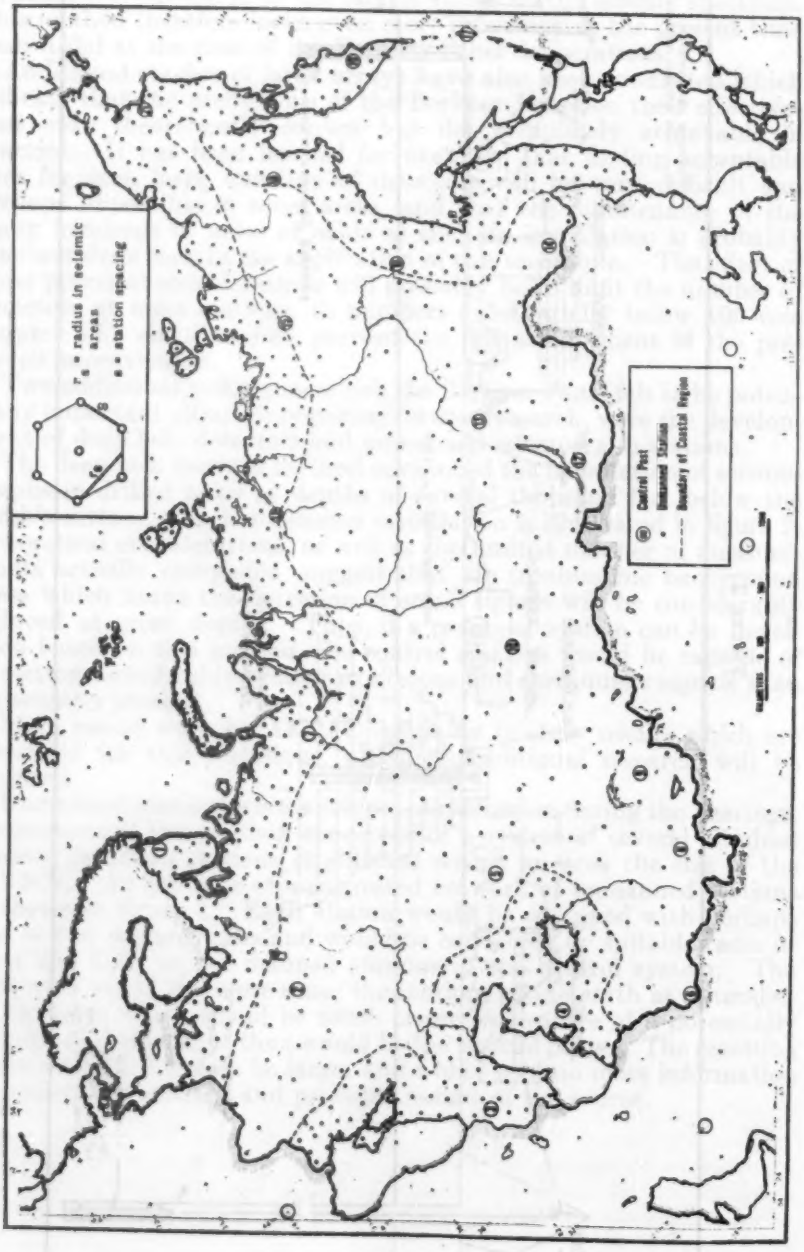

r = radius in seismic areas
s = station spacing
Control Post
Unmanned Station
Boundary of Coastal Region

FIGURE 3

A potential disadvantage of this technique is that the installation and periodic checking of the stations might require greatly increased access to the territory of the host country than would be necessary for the manned control post system alone. A further disadvantage of the unmanned stations is the very difficult problem of insuring that they are tamperproof. It would therefore be important to design the stations in such a manner that a minimum number of visits by foreigners would be required. At the same time due precautions should be taken to insure that the control system is provided with reliable data from the unmanned stations.

Dr. Hans Bethe in testifying before the committee on April 20, 1960 proposed a network of about 600 unmanned seismograph stations in the U.S.S.R. at intervals of about 125 miles. This network would be designed to identify a high proportion of the earthquakes equivalent in size to a 20 kiloton fully decoupled explosion (about 70 tons closely tamped).

Witnesses agreed that this method has the distinction of being the only technique so far suggested which could provide some capability for detecting decoupled nuclear explosions.

In a communication to the committee dated April 27, 1960, 7 days later, Dr. Bethe offered a revised statement which is printed in the appendix to the hearings. In this later statement he indicated that it would be possible, according to his new calculations, to reduce the number of unmanned stations in his proposal from 600 to 200.

He pointed out that the reduction in number of stations was possible since most of the U.S.S.R. is aseismic and that he believed it would be necessary only to detect seismic events in these areas. He estimated that the spacing of unmanned stations in the seismic regions could be 240 miles. Thus the closer spacing (125 miles which he suggested at the hearings) would apply only in the seismic regions of the U.S.S.R. (a relatively small percentage of the total area of the country).

Dr. Bethe pointed out further in his communication to the committee that high frequency recording, which he has suggested for his unmanned stations, will be particularly effective against decoupled shots since he believes the decoupling reduces only the average pressure rather than the initial pressure spike.

Finally, he expressed his belief that a system of unmanned seismic stations to supplement the present Geneva System would greatly increase the capabilities of the system to distinguish explosions from earthquakes of 1 kiloton equivalent and more and would thus greatly reduce the number of on-site inspections required.

It was noted that such networks would probably result in a large increase in the required number of on-site inspections, because such a dense network of stations would detect many more very small earthquakes which would require identification. There is very little data available on such small earthquakes. As a result, estimates of the number of on-site inspections of unidentified events resulting from the augmentation of the 1958 Geneva Conference Control System by 600 unmanned stations run as high as 500 per year.

The committee notes that the recommended method of improving the seismic detection improvement capability for detecting decoupled underground nuclear explosions through the use of increased numbers

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of seismic stations may possess the serious disadvantage of requiring an unrealistically large number of on-site inspections for identification purposes.

In addition to the methods described above, the Berkner Panel recommended a comprehensive research program in seismology to include the investigation of the fundamentals of seismic wave generation, propagation and detection.[1] It was felt that this program should be closely linked with a program for developing prototype stations for use in the control system. The Panel concluded that about 3 years' research effort would "probably result in future improvements which could achieve the same capability in the Geneva net of 180 stations as was originally estimated by the 1958 Geneva Conference of Experts." This evaluation of future capability did not take into account the estimated effectiveness of a system of unmanned stations, should such a system prove feasible.

[1] See chapter X.

## CHAPTER VI. INVESTIGATION OF THE USE OF LARGE SEISMOMETER ARRAYS IN THE U.S.S.R. FOR THE DETECTION OF UNDERGROUND NUCLEAR EXPLOSIONS

The committee heard testimony from representatives of the United Electrodynamic Corporation on a 2-month study of the problem of using large seismic arrays in the U.S.S.R. for detecting underground nuclear explosions. This study was initiated by AFTAC to determine the feasibility in practice of using arrays of up to 100 seismometers as recommended by the Berkner Panel on Seismic Improvement. The study covered an extensive investigation of array characteristics, a comprehensive study of the geological characteristics of possible locations for such arrays in the U.S.S.R. and the practical problem of engineering, installing and operating such arrays in a system of 22 stations within the U.S.S.R. at approximately the locations recommended by the Geneva Conference of Experts in 1958.

### DESIGN OF LARGE SEISMOGRAPH ARRAYS

The effectiveness of a properly designed seismometer array resides in the property that the earthquake or explosion signals from all of the individual seismometers of the array are summed in phase while the noises recorded by each of the seismometers of the array are summed out of phase. A large array can therefore be considered as a seismic antenna whose purpose is to increase the ratio between the amplitude of the seismic signal and the amplitude of the background noise at the station. Theoretically an "idealized array" will increase the signal-to-noise level over that recorded by a single seismometer by a factor equal to the square root of the number of elements in an array for incoherent noise. Thus, for example, a 100-element array should theoretically produce a seismic signal 10 times more outstanding above the background noise than would a single seismograph.

Actual field arrays cannot in general obtain full theoretical performance for a number of reasons; i.e. the difficulty in practice of finding a large number of ideal seismic locations, the fact that in actual terrain individual elements of the array will be at random distances and random elevations, the differential effects of wind noise on the various elements of the array, etc.

A study was made of the optimum size for a large array. If the array is made too small it will not be efficient in eliminating low-frequency seismic noise. If it is made too large it will attenuate the higher frequency signal components excessively. Transient tests of various size arrays were performed in a computing machine with actual nuclear explosion and earthquake signals. These tests showed that the proper diameter for a circular array of up to 100 elements is approximately two miles. Circular array shape is required to provide uniform response to signals approaching the station from any direction.

Studies were then made of 2-mile-diameter arrays including 31 elements, 85 elements and 97 elements in an array. It was found that the improvement in sensitivity of a practical installation is less than

that theoretically predicted for an idealized array by the amount indicated in the following table:

TABLE I.—*Comparison of practical and theoretical array performance*

| Number of seismometers in an array | Theoretical improvement | Practical improvement |
|---|---|---|
| 31 | 5.1× | 4× |
| 85 | 9.2× | 6× |

## ARRAY RECOMMENDATIONS

The performance from a practical array indicated in the above table shows only an improvement from 4 to 6 times in signal-to-noise level in going from 31 to 85 elements in an array. It was concluded that the relatively small improvement in performance does not justify installation of nearly three times as many seismometers. Arrays of 31 seismometers were therefore recommended, based on the following factors:

(*a*) In actual field practice it will usually be difficult if not impossible to find 85 "good" implacements within a 2-mile-diameter circle. It will sometimes be difficult to find even 31 good implacements.

(*b*) Because of large differences in noise levels at each of the different seismometer implacements it would be necessary to go through a "cut and try" process of relocating and improving the performance of individual seismometers in the array initially placed in noisier locations. For 85 positions this could be a very time consuming and nearly interminable process.

(*c*) With as many as 85 seismometers in a 2-mile circle the average separation of individual seismometers is not great enough to insure random response to noise on an efficient basis.

(*d*) Cost and difficulty of installation of an 85 element array are much greater than for a 31 element array.

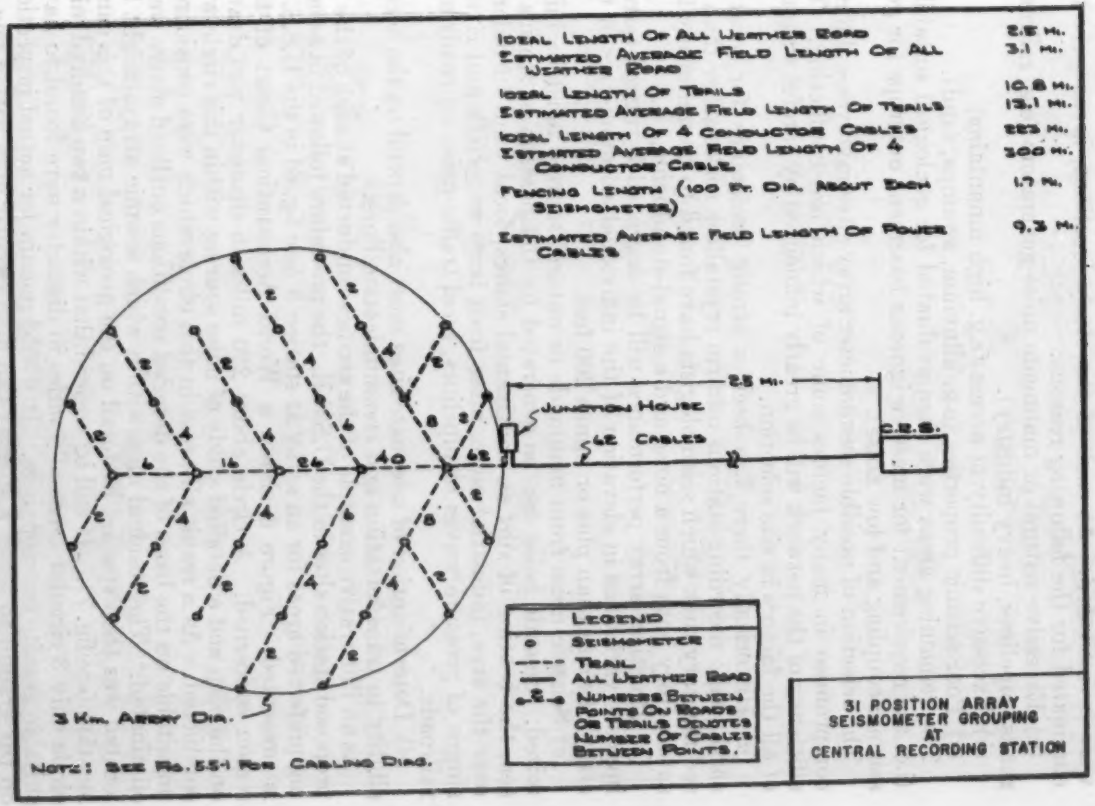
As a result of a study of the problem of installing practical field arrays, the configuration shown (see fig. 4) was recommended for installation in the U.S.S.R. The seismometers in the array are laid out on an interlocking hexagonal pattern in a circle approximately 2 miles diameter. It will be noted that the array is separated from the central recording station by a distance of 2½ miles.

In practice this distance may be as large as 10 miles depending upon logistic factors. Over this distance it will be necessary to run cables carrying both signal and calibrating circuits to each of the 31 seismographs in the array.

## SYSTEM OF LARGE ARRAYS OF SEISMOMETERS IN THE U.S.S.R.

The application of the recommended array design described above to a network of arrays throughout the U.S.S.R. was studied in detail. The principal task of this study was to determine the feasibility of locating 22 large seismic arrays in the U.S.S.R. Although these locations in the U.S.S.R. were not officially proposed by the Conference of Experts they represent a careful attempt to "lay out" a network with approximately 1,000 miles (1,700 kilometers) spacing in aseismic areas and 600 miles (1,000 kilometers) spacing in areas of

FIGURE 4


IDEAL LENGTH OF ALL WEATHER ROAD 2.5 MI.
ESTIMATED AVERAGE FIELD LENGTH OF ALL WEATHER ROAD 3.1 MI.
IDEAL LENGTH OF TRAILS 10.8 MI.
ESTIMATED AVERAGE FIELD LENGTH OF TRAILS 13.1 MI.
IDEAL LENGTH OF 4 CONDUCTOR CABLES 223 MI.
ESTIMATED AVERAGE FIELD LENGTH OF 4 CONDUCTOR CABLE 300 MI.
FENCING LENGTH (100 FT. DIA. ABOUT EACH SEISMOMETER) 1.7 MI.
ESTIMATED AVERAGE FIELD LENGTH OF POWER CABLES 9.3 MI.
2.5 MI.
JUNCTION HOUSE
42 CABLES
C.R.S.
2
4
8
12
14
24
40
42
3 Km. ARRAY DIA.
NOTE: SEE FIG. 55-1 FOR CABLING DIAG.
LEGEND
SEISMOMETER
TRAIL
ALL WEATHER ROAD
NUMBERS BETWEEN POINTS ON ROADS OR TRAILS, DENOTES NUMBER OF CABLES BETWEEN POINTS.
31 POSITION ARRAY SEISMOMETER GROUPING AT CENTRAL RECORDING STATION

high seismicity, in accordance with the recommendations of the Conference of Experts on spacing of the Geneva System. As can be seen by the chart (see fig. 5) the 600 miles station spacing matches fairly closely the zones of highest seismicity.

At each of the station locations shown in figure 5, the geographic, geological and topographic aspects of 22 proposed station locations were investigated. At each of the study locations, areas were first eliminated for the following reasons:

(*a*) Excessive natural or manmade noise generators (e.g. railroads, roads, pipelines, heavy industry).

(*b*) Excessive difficulty of access (e.g. high mountains).

(*c*) Poor seismic properties (e.g. alluvium, swamps, sand).

The remaining areas were then evaluated for geological suitability (i.e. the requirement for massive igneous basement outcrops for good seismic coupling and low noise).

The selection of possible seismometer array sites involves a difficult compromise in many factors some of which are conflicting. The efficiency of the network will be greatly influenced by careful weighing of all the factors in site selection.

(*a*) Historically there has been a strong preference for locating earthquake recording stations on firm crystalline rock rather than on sedimentary rock which seismologists have found to be uniformly less satisfactory both from a noise and a signal standpoint.

(*b*) Practical array performance will be degraded if rugged terrain imposes variations in elevation of the individual seismometers in the array of more than plus or minus 200 feet.

(*c*) Seismic noise from manmade or natural sources must be minimized. Seismic noise can be generated by the passage of storms at sea, the beating of surf on continental shores, local wind turbulence over the area, industrial noise, noise from large waterfalls and rivers, surges of pressure waves in pipelines, local traffic noise on roads and railroads.

(*d*) Determination of adequate sites must also depend on the accessibility to transportation and communication lines.

As an illustrative example of the studies conducted at each of the 22 proposed station sites in the U.S.S.R., the procedure followed in selecting preferred areas for an array at station 9 (see fig. 6) in the U.S.S.R. is presented. Figure 6 shows a World Aeronautical Chart of the region concerned. A circle about 200 miles in diameter was drawn on the map and a detailed study of noise sources within this circle was conducted. As a result all areas in this circle which were considered unsuitable on the basis of the detailed conditions outlined above were eliminated. The residual area within which seismic arrays might be located was then studied in detail on the geological map of this same location (see fig. 7). It will be noticed that within a two hundred mile circle only 3 circular areas of 6 miles in diameter were found to have suitable granite outcroppings. It would remain for actual inspection on the ground to select a specific two mile circular area within one of the three small circles shown (see fig. 7).

ARCTIC OCEAN
U S S R
CHINA
SWEDEN
FINLAND
POLAND
AFGHANISTAN
PAKISTAN
IRAN
IRAQ
BLACK SEA
DISTRIBUTION OF EARTHQUAKES

FIGURE 5

FIGURE 6

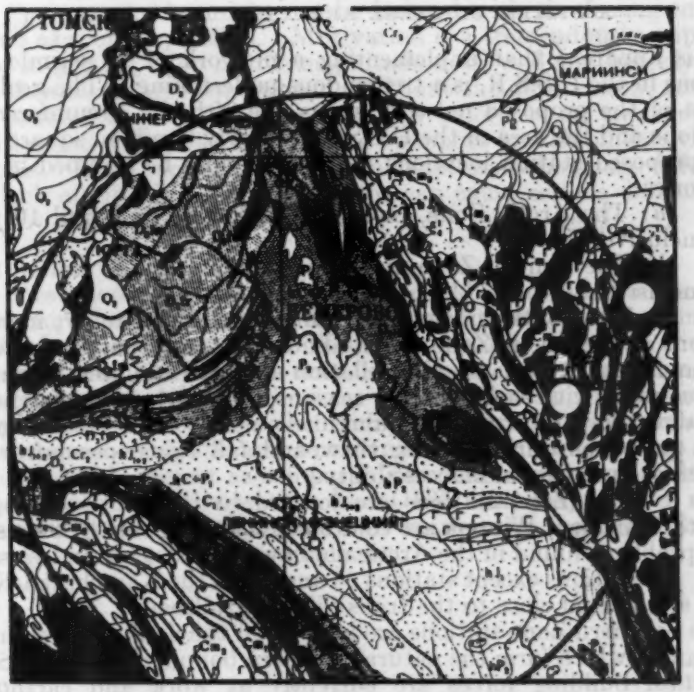
Station 9 is unusually well located as far as accessibility is concerned. It is definitely not typical of the remote and inaccessible regions far north in Siberia. However, this example does illustrate some interesting points which cannot be answered by map studies alone.

(*a*) The preferred areas show local farm roads. The U.S.S.R. would be required to cooperate in rerouting the roads to avoid local traffic noise at the station.

(*b*) If preferred sites fell on farmland, the U.S.S.R. would be required to exercise the "right of eminent domain."

(*c*) Since most roads are not hard-surfaced, year-round operations would require that the U.S.S.R. build miles of hard-surfaced roads.

FIGURE 7




Similar detailed studies were carried out in the other 21 locations in the U.S.S.R. In some instances no "preferred" sites were found in the 200-mile circle and it was necessary to shift stations several hundred miles to find more suitable conditions. The following table summarizes the results of the survey as far as access and geology are concerned:

TABLE 2. *Evaluation of locations chosen for a Geneva-type system in the U.S.S.R.*

| Geology | Access | Number of stations |
|---|---|---|
| Good | Good | 9 |
| Do | Fair | 5 |
| Do | Poor | 2 |
| Fair | Good | 2 |
| Poor | do | 3 |
| Very poor | Fair | 1 |
| Total | | 22 |

In summary, 16 of the 22 stations are on good geology with 6 on fair, poor, or very poor geology. Thus 27 percent of the stations may exhibit a degraded capability for detection.

### PROBLEMS INVOLVED IN INSTALLATION AND OPERATION OF A SYSTEM OF LARGE ARRAYS IN THE U.S.S.R.

It is apparent that implementing a network of 22 seismic array stations in the U.S.S.R. is a tremendous undertaking. The geological extent of the proposed network spans one-fifth the circumference of the globe and the area of the U.S.S.R. is nearly 9 million square miles. The proposed station locations (see fig. 5) may be grouped in three categories:

(*a*) The Arctic Zone, including stations 1 to 6 and 10 to 12, inclusive.

(*b*) The Central Zone, including stations 7 to 9 and 18 to 22, inclusive.

(*c*) The Southern Zone, including stations 13 to 17, inclusive.

Stations in the Arctic Zone are in about the same latitude as Alaska and far northern Canada. Installation and operation of the stations must contend with short summer seasons, long dark winters, temperatures down to −60° to −70° Fahrenheit, nearly impossible transportation problems during spring thaw and fall rains, permafrost soil conditions and general inaccessibility.

The Central Zone stations are located in the latitude range of Alberta, Canada. Winters are cold but not unbearable. Some of the same problems found in the Arctic north would exist but in less severe form. All stations except stations 20 and 21 on the Kamchatka-Kurile chain are located close to the trans-Siberian railroad.

The Southern Zone stations are located on the flanks of high mountain ranges which form the natural southern boundary of the U.S.S.R. Mountain building forces are currently at work and earthquake activity is intense. Except for location 13 near Tiflis, these stations are located in desert terrain. Heavy snow falls in the high mountain ranges, but valleys are dry and very hot in the summertime.

The volume and weight of material, equipment and supplies and the magnitude of construction projects is impressive. Depending on the specific array design, from 3,000 to 21,000 miles of special high quality cable will be required. Tens of thousands of telephone poles and hundreds of miles of steel messenger cable must be installed and hundreds of miles of roads and trails must be constructed and maintained. One or two thousand seismometers must be carefully placed at well-chosen locations, trees must be cut down, many miles of fences must be built. Many miles of roads must be rerouted, airfields must be constructed, farms and farmers must be relocated. Power plants, powerlines, water supply and sewage facilities must be constructed, an extensive communication system must be provided, heating and air-conditioning depending on the locations of stations must also be provided. Thousands of barrels of fuel will be required, many trucks, vehicles, bulldozers, cablehandlers, augers, steam jets, trucks, and tractor trailer trains and ice breakers must be provided and maintained.

The construction of the DEW line was a historical accomplishment. It required a 32 months crash program and involved expenditure of billions of dollars. In many ways the program contemplated here presents a similar challenge and offers problems in some ways more difficult and unique than the DEW line which was built on "home soil" by American and Canadian personnel.

A seismograph network in the U.S.S.R. would presumably be built with "partners" who might not be imbued with the feeling to finish the job as soon as possible. Motivation is a tremendously important factor in getting a job of this magnitude done well and quickly under difficult and adverse conditions. Without this motivation, construction could drag out for years with low priorities on transportation facilities and difficulties in "clearing" supplies and shipments through customs. Even such seemingly simple matters as language differences and lack of effective communications can cause serious difficulties.

### COSTS

It is estimated that the large arrays could be installed in the Soviet Union for about $75 million for 31 element arrays and about $100 million for 85 element arrays. This includes only the array, the cables and cable junction box. It does not include costs of airfields, roads, sewage disposal, water and power supplies, housing for instruments and personnel nor costs of icebreakers, tractor trains, transport aircraft, and many other logistic and communication facilities.

Viewing this project as comparable in difficulty and more extensive in geographical coverage than the DEW line project it is roughly estimated that the total cost for 22 stations in the U.S.S.R. would amount to one to five billion dollars.

## CHAPTER VII. ON-SITE INSPECTION

The objective of onsite inspection is to determine positively whether or not a suspicious seismic event resulted from a nuclear explosion. Of course, if through decoupling or other means, the seismic signal is too weak to be detected or the signal characteristics identify the event as an earthquake there would be no basis for onsite inspection.

As outlined by Dr. Richard M. Foose, on-site inspection may be considered to proceed in three phases. The first would consist mainly of aerial reconnaissance and would have as its objective reducing the size of the area to be inspected from the original 40 to 200 square miles to several areas each 1 to 5 square miles. In the second phase, mainly ground reconnaissance, the endeavor would be to reduce further the area to one having a radius of 500 feet or less. It may be possible at the conclusion of phase 1 or phase 2 to decide that the seismic event was an earthquake. If not, the third phase would involve drilling in this restricted area with the objective of searching for a sample of radioactive debris. A summary of available inspection techniques is shown in table I along with the phase in which they can be used and the approximate accuracy of location of the seismic epicenter they may provide. The techniques may be grouped into four classes, namely (1) visual and photographic, (2) surveying, (3) geophysical, and (4) geochemical.

TABLE I.—*Summary of the applicability of on-site inspection techniques*

| Technique | Phase of inspection [1] | Environmental use [2] | Approximate precision of location of epicenter (in feet) |
|---|---|---|---|
| Observation | R I D | A G U W D | Hundreds. |
| Photographic analysis | R I D | A G U W D | Hundreds. |
| Radiation surveys | R I D | A G U D | Hundreds. |
| Mensuration | I | G U | Tens. |
| Seismic noise monitoring | I | G U | Hundreds. |
| Seismic profiling | I | G W | Hundreds. |
| Electrical surveys (electromagnetic) | R I D | A G U W D | Tens. |
| Magnetic surveys | R I | A G W | Tens. |
| Infrared surveys | R I | A | Hundreds. |
| Acoustic surveys | R I | W | Hundreds. |
| Neutron logging | D | D | |
| Geothermal logging | D | D | |
| Acoustical logging | D | D | Hundreds. |
| Thermal gradient | I | U | |
| Geochemical analysis—soil | I D | G U D | Hundreds. |
| Geochemical analysis—water | I D | G U W D | Thousands. |
| Biogeochemical analysis | I | G | |
| Gravity surveys | None | A G U | |

[1] R=Reconnaissance (mostly air), phase 1. I=Intermediate, phase 2. D=Drilling, phase 3.
[2] A=Air, G=Ground, U=Underground, W=Water, D=Drilling.

### AERIAL RECONNAISSANCE

In aerial employment visual and photographic methods can identify and differentiate between unconcealed nuclear explosions and major earthquakes but not between a contained nuclear explosion and an earthquake of the comparable magnitude. Aerial surveys for gamma

radiation from surface sources would be useful only if the nuclear explosion vented slightly to the atmosphere but could never identify an event as an earthquake. Airborne magnetic surveys would be useful for the detection of ferromagnetic objects which might be associated with human activity. Airborne electromagnetic surveys would be used to detect nonmagnetic conducting material. Infrared detectors to measure temperature variations on the surface are not likely to detect the heat generated by a nuclear explosion at containment depth but may detect the heat from poorly concealed small sources.

### SURFACE INSPECTION

Visual examination on the ground would be limited by rugged terrain, snow and ice and heavy vegetation. Most earthquakes, except small ones, will produce surface alterations which can be detected by a trained observer; however, a deeply buried explosion will not produce noticeable changes in surface appearance. Ground surveys to detect the vertical motion of the earth's surface may be a potential method for identifying a seismic event but may be limited by rough topography in the area. Measurements of horizontal motion are only useful in the case of major earthquakes. Radiation surveys are useful if the nuclear explosion vents. Surface magnetic and electromagnetic surveys have a limited usefulness in the detection of artifacts. Seismic refraction and reflection techniques might be used to detect cavities produced by nuclear explosions and warrant further evaluation. Recording of aftershocks following an explosion has potential value though it may be limited by natural microseisms; but, in any case, an extensive research program on aftershocks from natural and artificial seismic events would be required to evaluate any locally recorded seismic signal as due to an aftershock. Geochemical analysis of soil would be useful if the explosion vented while geochemical analysis of ground water has low potential usefulness except where there is rapid movement of water. Biochemical analysis of plant life for absorbed radioactive fission products does not appear promising.

Techniques useful for inspection underground or in a marine environment differ only in detail from those used in land surface detection. In the underground environment human activities would be more closely confined and geologic features more readily recognizable because of better exposures. In an operating mine, activities associated with setting off a nuclear explosion may be difficult to distinguish from normal and legitimate mining operations. In marine areas the fluid nature of the environment would almost immediately erase surface manifestations of a seismic disturbance whether from an earthquake or nuclear explosion. Detection of artifacts such as drill casing and marine cable required in conducting the explosion offers the best potential.

### DRILLING

The final phase of on-site inspection—drilling—involves numerous associated techniques such as sonic, photographic, radiation and neutron logs, electrical logging, geothermal surveys, and petrological and mineralogical analyses of drill cores and cuttings. These serve to expedite and control the drilling process which is aimed at collecting a sample of radioactive fission products as positive evidence of a nuclear

detonation. Unless the first two phases of inspection result in selecting a reasonably small area, preferably less than 500 feet in radius meriting drilling operations, little success can be expected from the drilling phase. Indiscriminate drilling with the hope of intersecting a target appears to be out of the question because of the time and expense involved. It has been estimated that to insure discovery of a cavity or shattered zone produced by a 20 kiloton explosion within a circular area of 3 square miles would require drilling 250 holes to scaled depth at a minimum cost of $1½ million and take 2 years to complete.

Assuming that the epicentral area has been defined by phases 1 and 2 to an area 500 feet in radius, the following table indicates the number of drill holes in a triangular grid pattern that would be required to insure 100 percent completeness of the search for a radioactive zone of specified radius at a depth that would insure no surface disturbance from the explosion.

| Yield (kilotons) | Depth (feet) | Approximate radius of radioactive zone (feet) | Number of holes | Total drill footage |
|---|---|---|---|---|
| 1.7 | 1,200 | 60 | 63 | 75,600 |
| 20 | 2,700 | 150 | 10 | 27,000 |
| 100 | 4,700 | 250 | 4 | 18,800 |

The estimated time and cost to drill the required footage at the rate of 25 feet per shift, 3 men to a shift, and $5 per foot (exclusive of mobilization costs) is shown below:

| Footage | Cost | Time (days) | | |
|---|---|---|---|---|
| | | 1 shift/day | 2 shifts/day | 15 shifts/day |
| 75,600 | $378,000 | 3,024 | 1,008 | 202 |
| 27,000 | 135,000 | 1,080 | 360 | 72 |
| 18,800 | 94,000 | 752 | 251 | 50 |

If only a specified number of holes were drilled in a square grid pattern within the area of 500 ft. radius, the probability of discovery of the radioactive zone is shown below:

| Yield (kilotons) | 5 holes | 10 holes |
|---|---|---|
| 1.7 | 0.03 | 0.12 |
| 20 | .26 | .94 |
| 100 | 1.00 | 1.00 |

Thus, five drill holes would provide a 26 percent chance of discovering the radioactive zone from a 20-kiloton explosion occurring at a depth of 2,700 feet somewhere within the circle of radius 500 feet.

The above drilling figures were calculated for a nuclear explosion in Nevada tuff. If the explosions were to take place in a more homogeneous and denser medium such as granite, the explosion effects would be expected to be smaller. Therefore a large number of holes would have to be drilled to provide the same probabilities of success in drilling. The dollar costs and manpower estimates shown above would therefore have to be increased.

### EXPERIMENTAL INVESTIGATION OF ON-SITE INSPECTIONT ECHNIQUES

The only attempts to evaluate the on-site inspection techniques were made during the Hardtack II and Cowboy tests. Though the results were not available on the latter tests, at the time of the hearings, it can be stated that there were no terrain effects whatever. The techniques tested included visual examination, photographic and radiation surveys from the air, on the surface and underground; and seismic noise monitoring and vertical displacement surveys on the surface. Limited observations were made by means of seismic profiling and water analyses, but none of the geophysical techniques—magnetic, electrical, electromagnetic and gravity—were studied.

It should be noted that no attempt was made in the Hardtack II series to conceal any of the underground explosions. All could have been planned and executed at a depth to insure containment and preclude physical alteration of the surface of the earth. Any evaluation of the techniques must be considered in the above context and in the light of the fact that the precise locations of the explosions were known so that the important environmental characteristics were studied before as well as after the detonation.

All of the Hardtack underground explosions produced some surface manifestations. Blanca (19 kilotons), Logan (5 kilotons) and Neptune (90 tons) all produced unmistakeable surface evidence in the form of fractures, rock displacement and vegetation disruption visible to direct aerial observation and photography. The Rainier explosion (1.7 kilotons) of a year earlier also was clearly identified by observation and aerial photography. The Tamalpais (72 tons) and Evans (55 tons) events were not identified from the air. The evidence of human activity served to define the Hardtack test area very clearly. Visual examination on the ground and underground served to define the location of each explosion to within a radius of 100 feet with the possible exception of Tamalpais.

Attempts were made to listen to aftershocks with geophones following the Evans, Logan, and Blanca explosions. Some were recorded, but the equipment was operated only for a limited time and no evaluation of this technique could be made.

Vertical displacement, occasioned by subsidence of the surface following Blanca, was measured over a period of 90 days by the use of liquid-level gages. This showed that if the explosion depth is not such as to preclude surface subsidence, this technique is capable of clearly defining the epicenter.

### DETECTION OF CAVITIES AND FRACTURED ZONES RESULTING FROM UNDERGROUND NUCLEAR EXPLOSIONS

If a clandestine underground undecoupled (tamped) nuclear explosion is conducted by a determined party, very careful attention would be paid to removing all evidence which might enable an inspection team to locate the epicenter with sufficient precision to commence drilling operations. Then the only evidence of the explosion would be the physical effects in the immediate vicinity of the explosion.

It was recommended by Dr. Beers that seismic profiling be used to detect the cavity and the fractured zone. This method uses the exploration seismograph, similar to the earthquake seismograph but adapted to record the sesimic waves generated by a small explosion in a shallow tamped hole. The seismic waves from this explosion

radiate in all directions into the earth where they are reflected and refracted. Some then return to the surface and by close examination of recorded waves information may be gained as to the structure, attitude and condition of the subsurface rocks. This method of exploration has been successfully used in the search for petroleum, mineral and water resources and in engineering problems such as highway design and construction. Its application to the detection problem is new.

An arrangement of the shot holes, seismograph instruments and seismic wave reflection is shown in figure 8. The 24 seismographs are located in a line at 100 foot intervals and begin recording just prior to firing the shot. A dynamite charge is set off in a well-tamped shallow hole and the resultant seismic waves recorded. Those traveling along the earth surface appear first on the seismograph recording, followed by those which are reflected back to the surface by the various substrata of rocks. The arrival time of these waves is measured with a precision of one-thousandth of a second which represents a precision in depth of 5 to 7 feet. Measurements can be made to depths of 10,000 feet or more.

In practice, the line of instruments is moved along the profile a quarter of a mile at a time and at each new location a shot is fired from the central shot hole. After a profile is mapped, parallel profiles are run so as to cover the target areas as completely as possible.

When the reflecting strata are regular, smooth, and continuous in extent along the profile, the reflected waves have a regular appearance as illustrated in figure 9. But when the rocks at depth are fractured or faulted so that there is a discontinuity along the profile, the reflected waves are irregular (fig. 10). The interpretation of the seismic recordings in terms of the subsurface structure necessitates a thorough knowledge of the nature of the rocks and their folding and faulting in the general area to be inspected to prevent incorrect interpretation of the profile recordings. Therefore, some profiles must be mapped in the area surrounding the target to determine the normal geological structure unperturbed by an underground explosion. As long as the reflected waves recorded in the target area closely resemble those characteristic of the general geology of the area, no detection has been accomplished. But as soon as departures from the normal are noted, such as irregularities in times of arrival, wave amplitudes and phase relations among the various traces, the search may be intensified by recording along closer spacing in order to pinpoint the cavity zone. Thus the precision of location of the cavity can be of the order of a few tens of feet.

If the initial search has narrowed the target area to about 10 square miles, about 500 shot points and profiles should be used to cover this area. A party composed of about 10 men, 2 drills and 5 trucks can complete about 200 profiles per month at a cost of about $250 per profile. Over water such as the Gulf of Mexico a party with two vessels can run up to 1,000 profiles per month at about $125 per profile.

This method is recommended by Dr. Beers for inspection over sedimentary formations where the layering will produce several reflections. The refraction method would be more effective over salt domes since it is usually difficult to interpret reflection recordings around salt domes. To properly evaluate the usefulness of this technique, tests would have to be conducted.

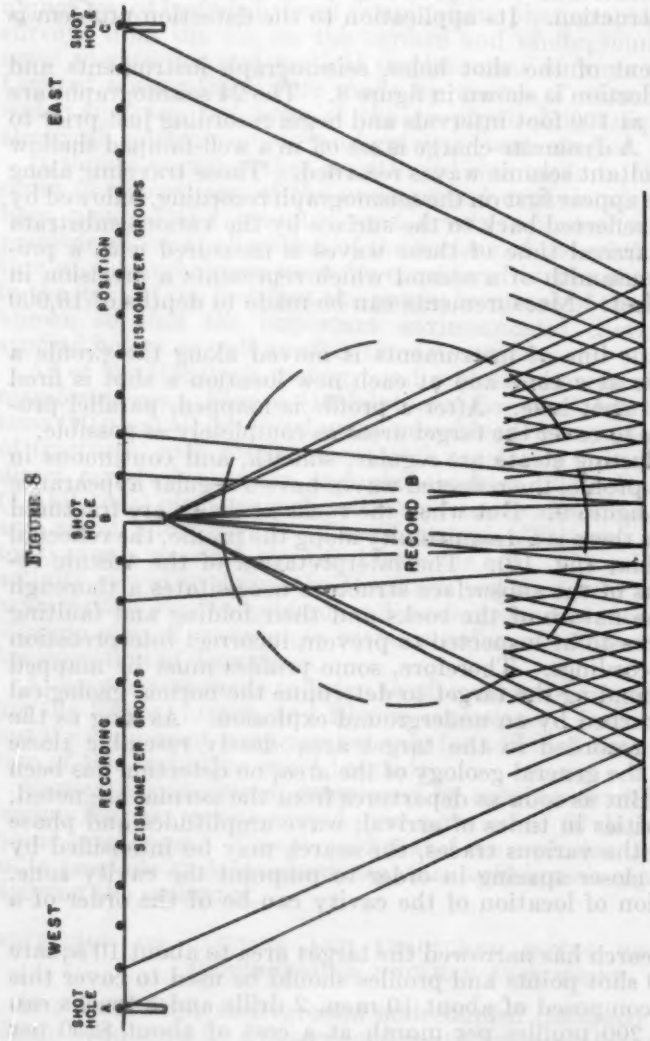

WEST
EAST
SHOT HOLE A
SHOT HOLE B
SHOT HOLE C
RECORDING SEISMOMETER GROUPS
POSITION SEISMOMETER GROUPS
RECORD B
REFLECTING HORIZON
SPREAD ARRANGEMENT FOR CONTINUOUS CORRELATION
SPLIT SPREAD
24 TRACE EQUIPMENT

FIGURE 8

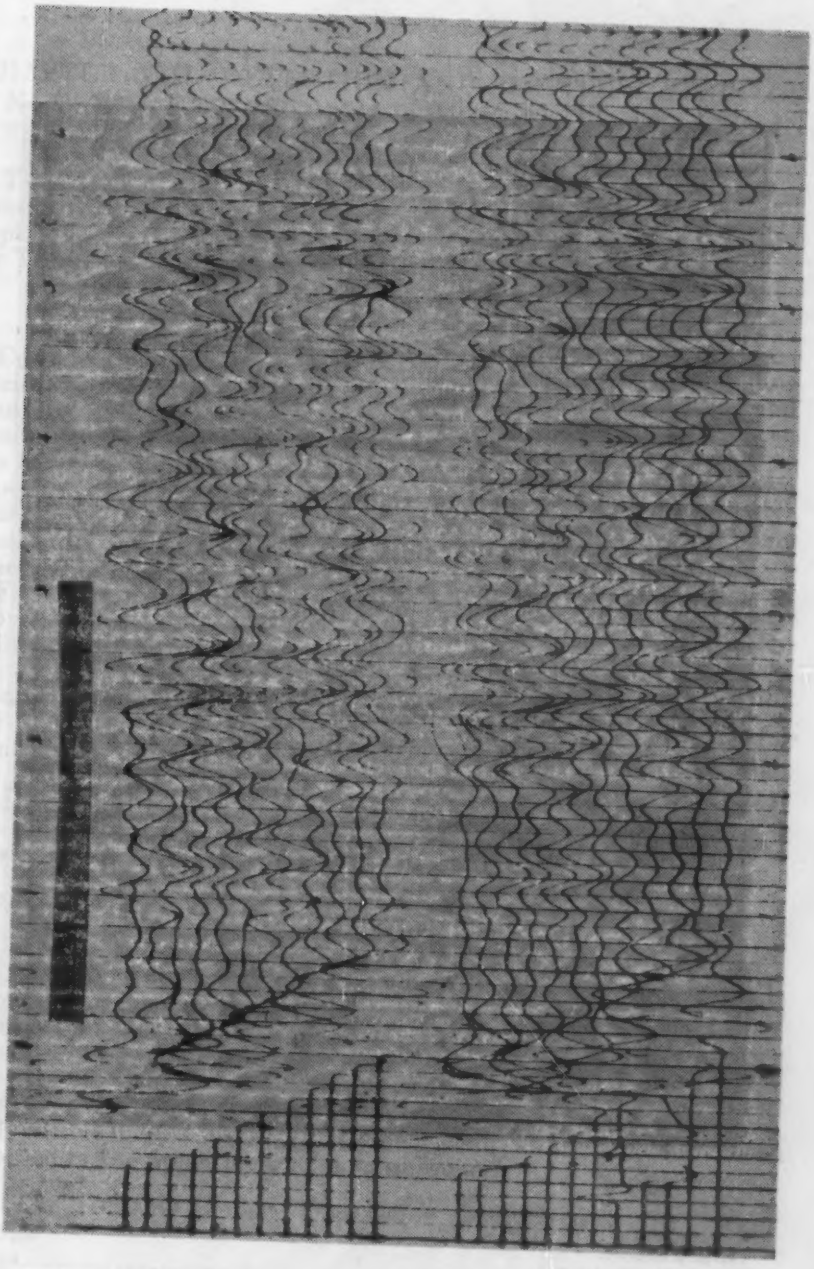


FIGURE 9

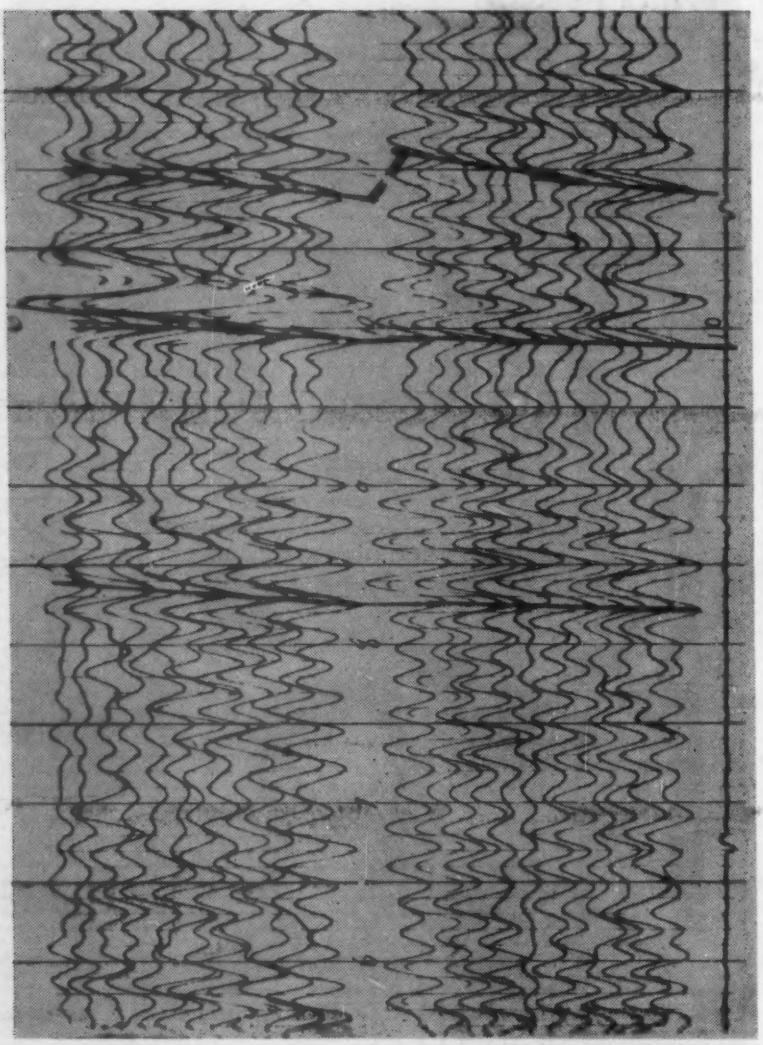


FIGURE 10

Faulted Reflection Record.

# CHAPTER VIII. DETECTION AND IDENTIFICATION OF NUCLEAR EXPLOSIONS AT HIGH ALTITUDE AND IN SPACE

The 1958 Geneva Conference of Experts made note of but did not consider in detail the problem of detection and identification of nuclear explosions at high altitude and in space. This subject was considered by Technical Working Group I which met in June and July 1959.

## FEASIBILITY OF TESTING NUCLEAR DEVICES IN OUTER SPACE

Consideration of the problem of control of an agreement banning nuclear testing in outer space by providing a means of detection and identification of nuclear detonations is based on the premise that such testing is possible in the foreseeable future. Testimony presented to the committee on this point indicated that, while there is no known experience in carrying out such tests, the basic technology is available today and could probably be applied effectively within 2 years. As specifically observed by Dr. Panofsky, nuclear tests in space are practical in principle.

For the purpose of limiting the space detection problem, Technical Working Group I decided to consider regions of space out to 200 million miles, approximately the diameter of the earth's orbit around the sun. It was felt that this was sufficient to cover all conceivable cases of possible violations of a nuclear test ban in space.

For a potential violator to consider testing at or beyond this range would require, with present-day rocket propulsion technology, that the violator wait for about one year after launch of a nuclear test vehicle before the vehicle reached its scheduled detonation point and test data was telemetered back to earth. From a practical point of view such a test program would be extremely lengthy and uneconomical.

## DETECTABLE RADIATIONS FROM OUTER SPACE NUCLEAR TESTS

Explosion of nuclear tests in outer space can be expected to result in radiation of particles and energy in several different forms, all of which can travel to great distances in the vacuum of outer space. Several of these radiations are listed in table 1 below, together with the duration and intensity of the signal at some distance from the detonation. Of these radiations, as pointed out by Dr. Panofsky, "only visible light reaches down to the ground; all the others would be absorbed in the upper layer of the atmosphere."

TABLE 1.—*Signals from nuclear weapons in vacuo*

| *Type* | *Duration of signal* |
|---|---|
| X-rays | 0.1 to 1 microseconds. |
| Prompt gamma rays | 0.03 microseconds. |
| Delayed gamma rays | 1 second. |
| Neutrons | Minutes. |
| Visible light | 0.1 to 1 microseconds. |

The types of radiation listed in table 1 are described as follows:

(*a*) X-rays are emitted due to the very high temperature of the nuclear device immediately after detonation.

(*b*) Prompt gamma rays are emitted in a very short time after detonation.

(*c*) Delayed gamma rays are those which continue to be emitted by the radioactive fission fragments for a substantial time after detonation.

(*d*) Neutrons, like gamma rays, may be considered in two groups, prompt and delayed. In the case of delayed neutrons, however, the effective time of emission is on the order of minutes. Unlike other radiations, neutrons travel not at the speed of light but at a variety of lower speeds to arrive at a detector over a substantial time interval, depending on distance from the source.

(*e*) Visible light is due to the incandescence of the nuclear device and is that small part of the thermal radiation emitted in the spectrum visible to the eye.

In addition to the radiations from a nuclear explosion described above, Technical Working Group I considered other secondary effects as possible tools for detection and identification. These were presented by Dr. Panofsky and described as follows:

(*a*) Visible light produced in the upper atmosphere when the X-rays from the detonation cause it to fluoresce.

(*b*) The change in the properties of the ionosphere due to absorption of energy from a nuclear explosion in space. This change affects the absorption and reflection of radio waves and is detectable, by—

1. The so-called ionospheric radar method.
2. The change in the strength of radio signals received on earth from outer space (cosmic noise receiver).

(*c*) The Argus effect. This name applies to the trapping of electrons in regions of the earth's magnetic field, the electrons having been emitted in the radioactive decay of fission fragments from a nuclear detonation at an altitude of a few hundred miles.

### IDENTIFICATION OF CLANDESTINE NUCLEAR TESTS

The problem of control of nuclear testing in outer space for the purpose of enforcing a ban on such testing by detection of violations has been presented to be substantially different from that of control of testing in the atmosphere or underground. For atmospheric tests, detection of radioactive debris from the detonation is considered to constitute identification of the explosion as being nuclear in nature. For underground tests, identification depends on on-site inspection. In the case of tests carried out at high altitudes, however, at least beyond distances on the order of 30 miles or in space, neither of these criteria for identification can be met. Dr. Panofsky pointed out that this raises the difficult problem of how reliable the detection of outer space explosions must be to constitute a basis for identification of the explosion as a test of a nuclear device.

### ESTIMATED RANGES OF DETECTION TECHNIQUES

In determining the distances at which the various types of radiations from a nuclear explosion can be detected, it was brought out that it is necessary to consider not only the strength of the signal from the ex-

plosion but also the strength of competing signals from natural phenomena which give similar radiations as, for example, the sun. Up until recently, scientific data on the nature and intensity of background radiation in outer space has been extremely scanty. Since the ranges of detection techniques are dependent on background as well as on signal strength, Dr. Panofsky describes the estimates of ranges given below as "fairly inaccurate."

Estimating ranges of detection techniques is further complicated by the possibility of a violator employing a shield in outer space nuclear test to minimize detectable radiations. Such a shield is conceived in principle to consist of additional material added to the nuclear test payload which would expand into a thin cylindrical shield on reaching the detonation point. The nature, quantity and shape of the shield material would be selected so as to reduce the detection signal levels. The manner of separation of the three components of the payload, i.e., the test device, the shield and the violator's test detectors, would be designed so that the shield would obscure detectable signals from the control system's detectors but not from the violator's detectors in the immediate vicinity.

Based on the considerations described above, the detection ranges of 11 techniques for detecting high altitude and space explosions were presented by Dr. Panofsky. They are summarized in the following table:

*Detection range estimated for unshielded tests of 1 to 10 kilotons* [1]

| *Method* | *Approximate theoretical range (miles)* |
|---|---|
| Direct optical | 300, 000 |
| Fluorescence | 500, 000 |
| Backscatter radar | 3, 000 |
| Cosmic noise absorption | 1,000 to 10,000 |
| Electromagnetic pulse | 3, 000 |

Techniques for employment on earth or solar satellites are listed in the following table:

| *Method* | *Approximate theoretical range (miles)* |
|---|---|
| Thermal X-rays | 200,000,000 |
| Prompt gamma rays | 300, 000 |
| Delayed gamma rays | 300, 000 |
| Prompt neutrons | 100, 000 |
| Delayed neutrons | 10, 000 |
| Trapped electrons | 30, 000 |

[1] These ranges would be increased by about 10 tons for a yield of 1 megaton.

## CONCEPT OF HIGH ALTITUDE DETECTION SYSTEM

In considering possible techniques for detection and identification of nuclear explosions at high altitude and in space Technical Working Group I agreed that all of the techniques shown above, with one exception, should be included, for the following reasons:

(*a*) The techniques supplement one another regarding their altitude and range capabilities in their sensitivity to shielding.

(*b*) The use of several techniques is essential because of the very difficult problem of identification of the signals from nuclear explosions.

The single exception to the agreement was the backscatter radar method, to which the U.S.S.R. representatives raised objections. According to Dr. Panofsky, the reluctance of the U.S.S.R. representa-

tives to consider the backscatter radar method on the same footing as the others appeared to derive primarily from concern that the method might detect other phenomena of military interest, e.g., missile passage through the ionosphere.

Selection of the techniques described depends on the degree to which radiations from nuclear devices penetrate the earth's atmosphere, ease and economy of use, and the geometrical problems of detection in space. As pointed out earlier, direct detection of X-rays, gamma rays, neutrons and trapped electrons is not possible on the earth's surface. Accordingly, these techniques must be used in satellite detection systems. All other techniques listed are usable only on the ground. Technical Working Group I recommended the following techniques for use at control posts:

(*a*) Direct optical.
(*b*) Atmospheric fluorescence.
(*c*) Cosmic noise absorption.

### SATELLITE-BORNE DETECTION SYSTEMS

Design of a system or systems of satellites for detection of high altitude or space tests was reported to be based on three prime considerations.

(*a*) It is necessary to insure that maximum coverage is given to all regions of space within about 200 million miles.

(*b*) For sufficient redundancy of signals to enhance the reliability of identification of detected signals as nuclear in origin, it is desirable to use as many different techniques as possible and as many satellites as reasonable.

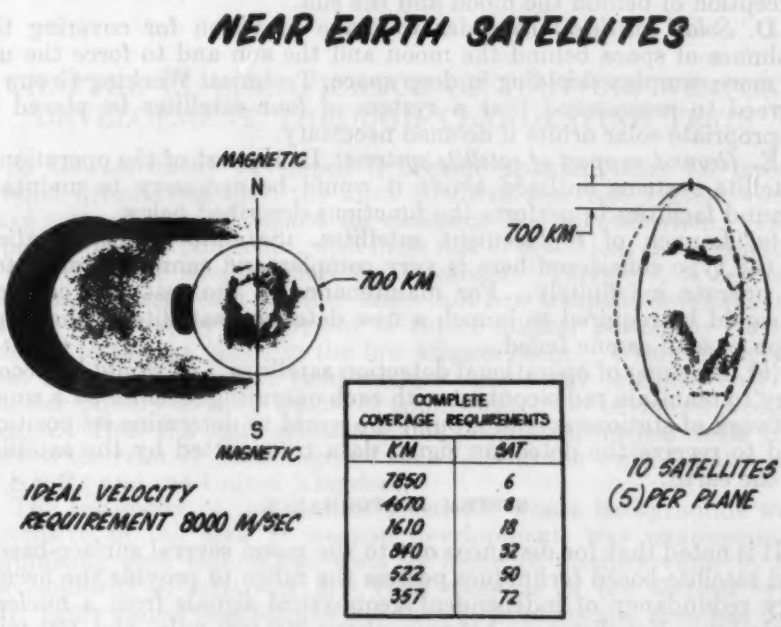
(*c*) The acquisition of much more data on background radiations in space which might resemble pulses of radiation from nuclear explosions in space and hence produce high false-alarm rates for the system.

Technical Working Group I recommended the following systems of satellites:

A. *Argus satellite:* A single satellite orbiting below the Van Allen belts in an appropriate orbit can intercept many times the trapped electrons from a single detonation in the earth's magnetic field. Technical Working Group I concluded that this tool would provide an inexpensive and powerful method of covering the region of interest.

B. *Near earth satellites:* Technical Working Group I proposed this system, illustrated in figure 11, as a possible alternative to the far earth system in the event it was desirable for economic or technical reasons. As shown in the figure, this system has the obvious disadvantage of requiring a larger number of satellites for full coverage.

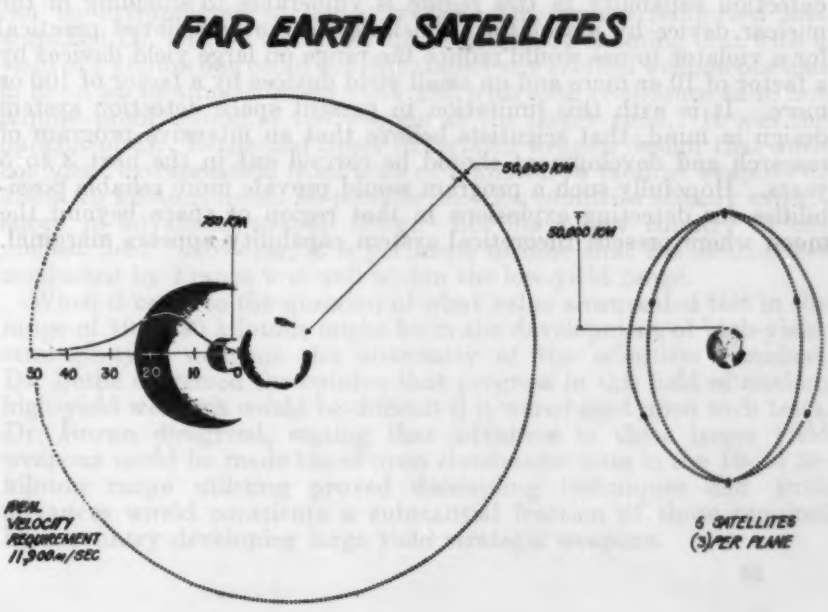
FIGURE 11




| COMPLETE COVERAGE REQUIREMENTS | |
|---|---|
| KM | SAT |
| 7850 | 6 |
| 4670 | 8 |
| 1610 | 18 |
| 840 | 32 |
| 522 | 50 |
| 357 | 72 |

C. *Far earth satellites:* For this system, it was recommended that about six satellites should be placed in orbit at above 20,000 to 30,000 miles. These six satellites positioned as shown in figure 12, would

FIGURE 12



provide full coverage of the surface of the earth and all space with the exception of behind the moon and the sun.

D. *Solar satellites:* In order to make provision for covering the volumes of space behind the moon and the sun and to force the use of more complex shielding in deep space, Technical Working Group I, agreed to recommend that a system of four satellites be placed in appropriate solar orbits if deemed necessary.

E. *Ground support of satellite systems:* In support of the operational satellite systems outlined above it would be necessary to maintain ground facilities to perform the functions described below.

(*a*) Launch of replacement satellites. Satellite instrumentation of the type considered here is very complex and cannot be expected to operate indefinitely. For maintenance of the test ban control, it would be required to launch a new detection satellite of the same type as soon as one failed.

(*b*) Tracking of operational detection satellites. It would be necessary to maintain radio contact with each operating satellite by a small network of stations spread around the world to determine its position and to receive the detection signal data transmitted by the satellite to the earth.

### SYSTEM PERFORMANCE

It is noted that for distances out to the moon several surface-based and satellite-based techniques possess the range to provide the necessary redundancy of independent geophysical signals from a nuclear explosion. For distances between above 300,000 miles and 100 million miles from the earth, however, only the satellite-based X-ray technique has the necessary range for detection.

This region of space is accessible by existing space vehicles for clandestine tests and is over 99.99 percent of the total volume of space available to a violator. The X-ray technique which alone provides a detection capability in this region is vulnerable to shielding of the nuclear device by a violator. Shielding currently believed practical for a violator to use would reduce the range on large yield devices by a factor of 10 or more and on small yield devices by a factor of 100 or more. It is with this limitation in present space detection system design in mind, that scientists believe that an intensive program of research and development should be carried out in the next 3 to 5 years. Hopefully such a program would provide more reliable possibilities for detecting explosions in that region of space beyond the moon where present theoretical system capability appears marginal.

## CHAPTER IX. SIGNIFICANCE OF FURTHER WEAPON DEVELOPMENT THROUGH CLANDESTINE TESTS

As the testimony developed it became apparent that for underground detonations even the most sensitive detection system would have some definite threshold for detection and identification. Thus a party to a test ban could, with little risk of detection, easily conduct a test of a size smaller than the threshold. Therefore, it becomes important to ascertain whether important new weapons developments can be achieved by the present or future nuclear powers by further nuclear testing at yields in the low kiloton range. Witnesses agreed that advantage of small yield nuclear tests could be taken only by nuclear powers already aware of sophisticated or advanced weapon design. Thus the main concern about small yield nuclear tests concerned the relative advantages of such tests to the United States, the U.S.S.R., and the United Kingdom.

The testimony of the various scientists, whose backgrounds were extensive in the area of weapon development, was unanimous in appraising such clandestine tests as being of distinct value in the development of relatively low yield weapons of the tactical type. Dr. Teller stated that tests of less than 20 kilotons and even less than 1 kiloton are exceedingly important in the development of tactical nuclear explosives and supported this contention with the fact that the great majority of recent U.S. test shots have been in this small kiloton range. Dr. Graves noted that even though one were restricted to testing below 1 kiloton one would not be restricted from developing weapons of greater than 1 kiloton yield since the results at low yields can be extrapolated to higher yields. Dr. Brown reinforced and amplified Dr. Graves testimony by categorically claiming that with a yield of 1 kiloton one could develop almost any tactical weapon one had in mind up to a much larger yield and with such confidence as to not require proof testing of the weapon at the larger yield. It was the opinion of Dr. Bethe and other experts in weapon design that such confident extrapolation from tests of a kiloton to tactical weapons of about 20 kilotons would be possible only for countries already experienced in advanced weapon design—not for a new country in the nuclear field. However, it is pertinent to note that the second test conducted by France was well within the low-yield range.

When it came to the question of what value a concealed test in the range of 10 to 30 kilotons might be in the development of high-yield, strategic-type weapons the unanimity of the scientists vanished. Dr. Bethe expressed the opinion that progress in this field of modern high-yield weapons would be difficult if it were based upon such tests. Dr. Brown disagreed, stating that advances in these larger yield weapons could be made based upon clandestine tests in the 10- to 30-kiloton range utilizing proved decoupling techniques and such advances would constitute a substantial fraction of those required by a country developing large yield strategic weapons.

In addition to clandestine tests underground, there is a possibility for clandestine tests in space. This is especially true prior to the installation of a ground-based or satellite-based detection system which may take years to develop. Even after the installation of such detection systems there would exist the possibility to devise technical means of carrying out an undetectable violation. Both Dr. Johnson and Dr. Leonard testified as to the technical feasibility of testing in outer space. Dr. Johnson stated that the basic measurements necessary to a weapon development program can be obtained with rather small extensions of already existing techniques for testing in space. If the basic principles of new weapon design could be obtained, with the detail required, by small underground detonations and if the proof testing of full-scale large-yield weapons could be conducted in outer space, then the entire development program would be conducted without risk of detection.

Finally, with respect to the overall, cumulative advantage that might accrue to the clandestine violator, Dr. Teller summed this up by stating that if the Russians were to continue testing clandestinely while the United States stopped they could overtake us in nuclear weapon technology in a very short time. Dr. Bethe expressed the opinion that advantages to the Soviets of additional clandestine testing are not of sufficient military advantage to justify the risk of detection.

In summary, the experts seemed to be agreed that present nuclear powers could achieve further advances in weapon design by further testing at small yields underground. Large scale proof tests might be conducted in space without detection. The experts disagreed upon the importance of such improvements in weapon development relative to the present state of nuclear weapon technology among the three leading nuclear powers. The experts did not discuss in detail the possibility that further testing might result in major technological breakthroughs which would give that nation achieving such breakthroughs a major military advantage over the other nuclear powers.

# CHAPTER X. REQUIRED RESEARCH AND DEVELOPMENT PROGRAMS

## A. Research and Development Required for Seismic Improvement

On March 31, 1959, the Berkner Panel on Seismic Improvement submitted its detailed report on the need for fundamental research in seismology. This report was subsequently released in full by the State Department in July of 1959. The proposed program was comprehensive in scope and dealt with a broad range of fundamental problems in seismology which bear on the detection and identification of underground nuclear explosions. The report also included recommendations for a program which would lead to the development of the actual instruments and hardware required for a worldwide seismic system for monitoring underground nuclear weapons tests. As a direct result of the recommendations of the Berkner Panel, the U.S. Government has embarked on a program of research and development in the field of seismology. Although certain planning actions were taken during the summer of 1959, the Advanced Research Projects Agency was not formally assigned the project until September 2, 1959. The program has been assigned the nickname "Project VELA UNIFORM." Following a sequence of technical and budgetary reviews, an initial small allotment of funds in the amount of approximately $800,000 was made available to the Air Force Technical Applications Center in October 1959 and authorization for the remainder of the program in the amount of $7 million was given on February 4, 1960.

A major task of Project VELA UNIFORM provides for equipping a large number of the world's seismological observatories with standard, calibrated seismographs and auxiliary equipment, to be maintained and operated by them as part of their normal activities. The data accumulated by these stations would be exchanged freely among seismologists throughout the world. This project has no direct bearing on the control system required for monitoring underground nuclear explosions. It is intended to provide a source of uniform and quantitative seismic data in support of research efforts directed toward understanding the nature of earthquakes and the characteristics of the seismic waves which propagate from them. Such data are presently lacking because of the diverse equipment employed at seismic observatories and because in most cases the existing equipment is not calibrated with the precision required. The U.S. Coast and Geodetic Survey of the Department of Commerce will procure this equipment and arrange for its distribution and installation. Procurement and distribution is expected to commence in mid-1960 for the first 50 sets of equipment. The National Academy of Sciences has established a committee of eminent seismologists to furnish advice on this project. This committee is currently preparing a report recommending specifications for the standard equipment and outlining a policy on where

the equipment should be installed and the obligations of the recipient stations with regard to operation of the equipment and exchange of the data.

The second major task entails the establishment of a large-scale basic research program on the generation and propagation of seismic waves. This work is designed to stimulate basic research in seismology at universities and other research organizations with eventual long-range benefits to the detection problem. It is anticipated, for example, that this project will result in an important increase in the number of trained scientists, some of whom will be essential in the operation and evaluation of the data from any control system which might be established as a result of the current negotiations on a treaty for nuclear test cessation. Work in this category includes such topics as investigation of characteristics of shear waves from explosions and earthquakes; studies of the frequency of occurrence and spatial distribution of aftershocks from earthquakes; studies of the generation and propagation of long-period and surface body waves and the development of equalization methods for determining the nature of the source from these waves; the investigation of the structure of the earth's crust and upper mantle and its influence on propagation of seismic waves; model studies; and the investigation of additional fundamental problems in seismology.

A more applied aspect of this project has to do with the development of new types of seismic instruments as well as techniques for their optimal employment in arrays. In parallel with these studies it is necessary to investigate the spectrum and coherence of noise and the variance in these characteristics which depend on geological and meteorological conditions. Unconventional approaches to detection are also being considered, including such devices as detectors installed and operated in deep holes at depths of several thousand feet below the earth's surface and on the bottom of the oceans.

The third major task is the systems development program. This is currently being conducted in two parts. First, a seismograph station employing all of the seismic equipment recommended by the 1958 Geneva Conference of Experts is currently being constructed at Fort Sill, Okla. The basic equipment includes an array of 10 vertical-component, short-period seismographs and 2 matching horizontal detectors, as well as three sets of 3-component seismographs with different frequency characteristics designed to cover the important parts of the seismic spectrum. The station is expected to be in operation by mid-1960 and will be operated for sufficient time to evaluate its performance and to develop improved techniques. Second, negotiations are under way to select a contractor for the design and operation of a systems development laboratory and seismograph station. In its initial form the seismograph station will be designed following the recommendation of the Berkner Panel on Seismic Improvement. The most modern equipment and techniques which can be specified at the present time will be employed at this facility. Installation and operational problems which would be encountered in employing such stations in a worldwide system will be investigated, as well as necessary data reduction and data transmission techniques. The characteristics of the station will be continually modified in light of the most recent technical advances in the detection art. The methods developed and the experience gained will be essential to establishing any final worldwide control system.

The fourth major task provides for a series of underground nuclear and high explosive detonations. These explosions are required to provide research data on the types of seismic waves generated by explosions and their amplitude and frequency characteristics. It is also essential to have nuclear and chemical explosions to test the performance of individual detectors and of systems of detectors used in any possible control system. Previous experience in detecting seismic waves generated by large explosions, particularly nuclear explosions, is very limited. Only three completely contained underground nuclear explosions with yields greater than one kiloton have been fired by the United States. All of these were detonated under similar environmental conditions at the Nevada test site. The parameters that can significantly affect the characteristics of seismic waves produced by nuclear explosions must be experimentally explored. Theories must be developed which will permit a better understanding of these paramenters and their effects on seismic waves. The dependence of the peak seismic signal in magnitude and direction of first motion on such factors as medium, depth of burial and geology must be determined. The latter is especially important because first motion is at present our only criterion for identifying earthquakes. The evaluation of the diagnostic aids which have been suggested for improving the Geneva system by the United States Delegation at Technical Working Group II also requires underground explosi ns. To answer some of these questions chemical explosives may be satisfactory. However, our ignorance on this point is so great that a satisfactory program must be based on nuclear explosions.

For decoupling experiments nuclear explosions are necessary because it is known that the difference between chemical and nuclear explosives is large for explosions in cavities. For the study of on-site inspection techniques nuclear explosions are also necessary, since for a given yield explosion, the engineering activity will be much less in the nuclear case.

A large measurement program is required for collecting the basic data to be used in developing improved detection and identification methods. This information will be derived principally from temporary experimental stations established at locations determined by the specific nature, size and location of the explosion. A typical measurement program will include accelerometers, velocity meters, strain and pressure detectors placed in bore holes above, below and at horizontal positions surrounding the shot, at distances from a few feet to a few hundred feet. The resulting measurements will be used to test theoretical predictions regarding the basic explosive phenomenology. When suitable theories have been developed and proved, it will be possible to predict effects at other yields and in other media, thus reducing the number of shots required.

At distances from about 1,000 feet to perhaps 50 miles, along the earth's surface, strong-motion acceleration and velocity measurements will be made in the frequency range below 100 cycles per second. The resulting data will be used to measure total energy input into seismic waves and to test theories on waveform distortion over relatively simple paths. About 6 strong-motion stations and 6 sensitive seismograph stations will be required. About twenty stations will be established at distances beyond 50 miles and extending to 2,000 or 3,000 miles from the site of the explosions. Generally, the stations will be

equipped with both short-period (about 1 second) and long-period (greater than 10 seconds) seismographs. As time and funds permit, recording systems will be converted from photographic to tape storage units to simplify performing more complex analyses. The majority of the improvements in detection will result from this data.

The research and development budget available for fiscal year 1960 and as requested for fiscal year 1961 is given below in table I. In comparison is the research and development program recommended by the Berkner Panel in March 1959 in table II below.

Testimony reflected that the fiscal year 1960 available funds were first allocated in December 1959 and that as of the date the hearings began, April 19, 1960, only $5 million had been obligated. Testimony also reflected that the fiscal year 1961 requested funds were not included as a line item in the Department of Defense fiscal year 1961 budget and that to be available these funds would have to be obtained from other Department of Defense projects or sources. It is noted that the funds requested for fiscal year 1961 appear to be twice the level of effort recommended by the Berkner Panel ($30 million) for the second year's research and development. Slightly more than one-half of the fiscal year 1961 requested would be for site preparation not included as part of the Berkner scientific R. & D. program.

TABLE I.—*Summary of existing and proposed budget for seismic research and development*

| | Fiscal year 1960 (available) | Fiscal year 1961 (requested) |
|---|---|---|
| 1. Equipment for standardized seismic research stations | $750,000 | $12,625,000 |
| 2. Research programs: | | |
| (*a*) Studies of generation and propagation of seismic waves | 2,350,000 | 6,200,000 |
| (*b*) Detection studies | 1,250,000 | 3,500,000 |
| 3. Systems development | 930,000 | 8,125,000 |
| 4. Large explosions: | | |
| (*a*) Site preparation | 880,000 | 32,500,000 |
| (*b*) Measurement programs | 1,430,000 | 10,490,000 |
| 5. Miscellaneous special studies | 195,000 | 300,000 |
| 6. Administrative costs | 50,000 | 100,000 |
| 7. Reserve fund | 700,000 | |
| Total | [1] 8,535,000 | 63,840,000 |

[1] As of April 1960, only $5,000,000 had been obligated.

TABLE II.—*Research and development program recommended by Berkner Panel, March 1959*

| | 1st year | 2d year |
|---|---|---|
| Individual research projects: | | |
| Equipping of selected stations with modern seismic equipment | $1,250,000 | $1,000,000 |
| Study of shear waves | 225,000 | 170,000 |
| Identification from aftershocks | 100,000 | 100,000 |
| Long-period surface and body waves | 1,000,000 | 1,000,000 |
| Geophysical investigation of crustal structure | 1,000,000 | 4,000,000 |
| Equalization experiments | 300,000 | 1,000,000 |
| Model studies | 100,000 | 100,000 |
| Noise studies and development of standards | 150,000 | 150,000 |
| Large arrays | 500,000 | 1,000,000 |
| Deep hole detection | 500,000 | 500,000 |
| Deep ocean seismograph | 400,000 | 400,000 |
| Research computing facilities | 750,000 | 750,000 |
| Library of digitized seismograms | 50,000 | 100,000 |
| Theoretical studies of explosion sources | 100,000 | 100,000 |
| Other | 150,000 | 150,000 |
| Subtotal | 6,575,000 | 10,520,000 |
| System development: | | |
| Unattended seismic stations | 750,000 | 1,250,000 |
| Improved seismographs | 300,000 | 300,000 |
| Portable or throwaway seismographs | 200,000 | 230,000 |
| Automatic data processing | 1,000,000 | 1,700,000 |
| System planning and field trials | 2,000,000 | 4,000,000 |
| Implementation of detection system | (1) | (1) |
| Subtotal | 4,250,000 | 7,480,000 |
| Nuclear and HE detonations | 12,000,000 | 12,000,000 |
| Total, (not including implementation) | 22,825,000 | 30,000,000 |

[1] Not estimated.

### ON-SITE INSPECTION

It has been recommended that research and development should be conducted for improving the capability of on-site inspection. It was apparent from the information presented at the hearings that the state of the art of on-site inspection is not very far advanced.

Although many scientific techniques have been suggested for possible application to this problem, it appears that most are limited to very short distances from the site. This puts a heavy responsibility on the methods of aerial surveillance and observations of recent human activity.

## B. RESEARCH AND DEVELOPMENT REQUIRED TO DETERMINE FEASIBILITY OF DETECTING NUCLEAR EXPLOSIONS IN SPACE

In addition to improvement of underground detection techniques as described in earlier sections, research and development effort on the part of the United States is being actively considered as a prerequisite to establishing with assurance an adequate capability of detection of nuclear detonations in space. The portions of Project VELA which pertain to high altitude detection are first, VELA SIERRA for the surface-based detection of high altitude detonations and VELA HOTEL for the space-based detection in the same areas.

### SURFACE BASED DETECTION TECHNIQUE RESEARCH AND DEVELOPMENT (VELA SIERRA)

In the case of each of the several surface-based techniques for detection of high altitude detonations, additional research and development is required, in varying degree, to develop these into useful components of a detection system. A brief review presented to the committee pointed out the following areas for investigation in two classes of techniques.

(a) For the optical methods, that is those detecting both the direct optical signal from the detonation and the secondary atmospheric fluorescence due to thermal X-rays, the basic components of the system need to be assembled into preprototype instruments and tested for response in the presence of natural phenomena before the capabilities of the instruments are well defined. Specifically, as Mr. Beyer testified, lightning flashes, the aurora and the presence of clouds may adversely affect their performance.

(*b*) For the electromagnetic methods other than light detection on the surface, broad areas of investigation need to be explored before the instrumentation can be designed or the data understood. For detection of the radio signal emitted by the explosion, it is necessary to gain an understanding of the characteristics of the signals obtained from a detonation at high altitude and to devise methods of discriminating against the natural signals due to lightning flashes.

For the detection methods which make use of the ionosphere disturbances caused by a nuclear detonation, perturbations due to natural causes, such as solar flares, must be investigated and understood before proper equipment design can be undertaken.

For the purpose of commencing the studies outlined briefly above, funds in the amount of $1,050,000 were allocated to the Advanced Research Projects Agency in April 1960. Additional funding is expected to be requested for further work.

### SPACE-BASED DETECTION TECHNIQUE RESEARCH AND DEVELOPMENT (VELA HOTEL)

As outlined for the committee by Mr. Beyer, a research and development program for the investigation of each of the factors affecting the design of an effective space-based detection system would include—

(*a*) Study of the basic mechanisms of nuclear weapon detonations in space.

(*b*) Determination of the natural radiation background in space where detection systems are to be used.

(*c*) A substantial effort toward the improvement of X-ray, gamma ray and to a lesser extent, neutron sensing devices with emphasis on advanced techniques.

(*d*) Substantial effort toward the improvement of the electronic analysis equipment, sometimes called the logics, which provide the capability for testing the significance of the signals received by the detectors, rejecting those due to natural causes and transmitting the remainder to the ground.

(*e*) Research into any promising detection schemes other than those derived from sensing X-ray, gamma ray, and neutron signals.

(*f*) Thorough investigation of all aspects of equipment reliability for the purpose of increasing the useful operating time and reducing system maintenance costs.

(*g*) Study of possible countermeasures to techniques for concealment designed to mask a nuclear detonation from a surveillance system.

For the purpose of detailed development and funding planning of methods of accomplishing the investigation described, a cooperative study on the part of the Air Force Ballistic Missile Division, the Atomic Energy Commission, the National Aeronautics and Space Administration, and associated contractors was completed in April 1960, and is now undergoing review by the agencies involved. The salient features of a study of the technical aspects of satellite detection of detonations in space, based on this development and funding plan, were submitted to the committee by Dr. Taschek.

Dr. Taschek, in his testimony, assumed that the detonation takes place beyond about 20,000 miles and that far earth satellites are the vehicles for the detection equipment. For the sensing equipment, the detection of X-rays, gamma rays, and neutrons is favored because of the existing advanced detector technology for these radiations and the high degree of predictability of the time history, intensity and energies of the emitted radiations. The general problems associated with this development effort include definition of the interference expected in the detectors due to background signals from natural phenomena and solution of the problem of reliability of the extremely complex electronic logics required to relay a detonation alarm back to the control station on earth.

An overall approach to the prototype detector system, presented as the most expeditious yet reasonably deliberate, is conceived to require, in addition to measurements of background radiations in space, low and high altitude test flights of instrument components and development of preprototypes with actual measurements of their responses to background radiations. On the basis of these preliminaries and with the use of well-understood detector techniques as may be modified by advances in detection science and technology, Dr. Taschek stated that "after placing three full-scale experimental satellites in orbit, the requirements for a successful prototype surveillance system should have been met."

For the experimental satellites, it is planned to proceed in development stages with the following detectors:

(*a*) *Neutron detector:* For this purpose, a simple device consisting of a single boron trifluoride neutron counter or a neutron sensitive scintillation crystal counter is proposed. Provision would be made for continuously measuring the background intensity, for recognizing a detonation signal by neutron counts significantly above background, and for recording and transmitting the time history of the neutron signal to the ground.

(*b*) *Gamma-ray detector:* For detection of gamma rays from a detonation, it is suggested that six scintillation counters distributed over the satellite would cover all directions in space and could be instrumented so as to distinguish the gamma-ray signal from a nuclear detonation by its extremely short time duration, about 30 billionths of a second. Provision would be made for avoiding false alarms due to cosmic ray particles.

(c) *X-ray detector:* Initial development work towards an X-ray detector is expected to make use of a thin plastic phosphor with photomultiplier. As many as 32 detectors may be used to cover all directions in space. For signalling alarm of a nuclear detonation, it is conceived sufficient to require detection by three-fourths of detectors facing the detonation point and a pulse shape from the photomultiplier similar to that expected. Later X-ray detectors may make use of the open photomultiplier system proposed by Dr. Panofsky for detection with much greater sensitivity. Detectors of this type require much more study than the other types proposed.

For the developmental stages leading toward a final operational satellite system, it was presented that carefully thought out prototype satellites have been considered. For the first experimental satellite, portions of the detection systems outlined above would be flown in conjunction with support experiments designed to determine the response of the preprototype detectors to the details of background radiations. This information would permit both changes in operating characteristics of the satellite detectors in flight by command signal and design changes in later models. Later satellites would progress more towards the full systems conceived with less support experimentation. For each of these experimental satellites, expected to be three in number, it was considered to be probable that a payload design sufficiently reliable to have a 90 percent probability of providing 3 months of data from flight test would be adequate for satisfactory completion of the development program.

The conservative development program outlined above is considered highly probable to lead to an operational system having the individual detection range for nuclear explosions occurring at distances a few times that to the moon. Concentrated development effort on the Panofsky open-photomultiplier X-ray detector may extend the range capabilities of the final operational system, but of itself, is not expected to overcome the problem of degradation of range shielding.

For the funding of the development leading toward an operational satellite detection system, Dr. Taschek submitted the estimates included in table 1, below. These estimates provide only for satellite payload costs. The scope of the funding estimates is based on the assumption that nine satellite launches would be required to have the three successful full-scale experimental satellites deemed to be required by the development study group.

TABLE 1.—*Estimated payload costs for satellite-borne detection system development*

[In millions of dollars]

| Fiscal year | Number payloads | Probe and piggyback experiment | Detector development and construction | Payload logics power and telemetry | Data reduction | Total |
|---|---|---|---|---|---|---|
| 1961 | 1 | 0.4 | 1.0 | 2.2 | ---------- | 3.6 |
| 1962 | 6 | .4 | 1.0 | 7.4 | ---------- | 8.8 |
| 1963 | 4 | .4 | 1.0 | 5.4 | 0.6 | 7.4 |
| 1964 | ---------- | ---------- | 1.0 | 1.4 | 1.2 | 3.6 |
| 1965 | ---------- | ---------- | .5 | .5 | 1.0 | 2.0 |
| Total | 11 | 1.2 | 4.5 | 16.9 | 2.8 | 25.4 |

### SATELLITE VEHICLE AND COMMUNICATION REQUIREMENTS FOR SPACE-BASED DETECTION SYSTEM DEVELOPMENT

In the interest of national security, detailed information was not elicited at these public hearings on the payload-orbit capabilities of existing or planned satellite launching vehicles. General testimony was received, however, through the representative of Mr. A. F. Donovan, Space Technology Laboratories, Dr. B. P. Leonard, to the effect that no dealy is anticipated in prosecution of research and development of the satellite-borne detection system due to lack of launching vehicles. Due to the time required to design and engineer the payload for the first full-scale experimental satellite, approximately 2 years, adequate opportunity exists for production of launch vehicles having the requisite characteristics for launch of the estimated necessary payload into a far earth orbit more than 20,000 to 30,000 miles altitude.

Tracking and receiving stations being established under other programs are reported to be considered adequate to track the prototype detection satellites, to transmit commands to the satellite payload instrumentation, and to receive and record data transmitted by the satellite.

### TIME SCALE FOR ACHIEVING HIGH ALTITUDE DETECTION CAPABILITY

For the purpose of summarizing the testimony presented to the committee on the time scale for completion of the required research and development and establishing an operational high altitude detection capability, including features providing only limited capability, listed below are possible milestones in the programs discussed on the assumption that all development efforts are initiated by July 1, 1960.

*January 1961:* Limited satellite-borne capability with neutron or trapped electron detectors and existing launch vehicles and support equipments.

*July 1961:* Approach to operational use of atmospheric fluorescence ground-based detector.

*July 1962:* Launch of first full-scale experimental satellite with threefold detection sensors in a far earth orbit.

*July 1964:* Definition of prototype operational satellite-borne detection system.

# APPENDIXES

## APPENDIX 1

### Glossary

*Accelerometer:* An instrument which is so designed that it responds to the accelerations of the earth relative to the suspended mass of the instrument rather than measuring either the velocity or displacement of the earth. This instrument is usually employed to measure the close-in strong motion from an underground nuclear explosion.

*Array:* A group of seismometers arranged in a systematic pattern over an area of a few square miles for the purpose of increasing the detectability for small earthquake or explosion signals in the presence of background noise.

*Backscatter radar:* Detection of change in the characteristics of the ionosphere resulting from absorption by it or energy from a nuclear detonation. The change in ionosphere characteristics changes the intensity of the radio frequency waves emitted by the radar transmitter and reflected (scattered) back to the radar receiver.

*Clear rarefactions:* The first motion recorded by a seismograph as a result of a distant earthquake may be either compression or rarefaction. In the first case, the first motion is caused by a movement of the earth outward from the source and in the second case, by a motion of the earth toward the source. Clear rarefactions are those which are large enough in amplitude above background microseismic noise to permit these rarefactions being identified without question as movements of the earth toward the source of the earthquake.

*Cosmic noise:* Incoherent electromagnetic noise signals (static) originating in cosmic space and propagated inward through the ionosphere to the surface of the earth where they are recorded on sensitive radio receivers called riometers.

*Coupling:* In this report, coupling refers to the amount of the total energy released in an underground explosion which is transformed into seismic waves in the earth. The greater the coupling of a particular explosion the larger will be the seismic waves and the easier it will be to detect by seismographs at some distance from the explosion.

*Cowboy Series:* A series of chemical explosions in a salt dome in Louisiana which gave experimental proof of the theory of decoupling.

*Decoupling:* The process of reducing the size of the seismic signals from an underground explosion by detonation of the explosive in a large hole underground.

*Deep focus:* A term used by seismologists to indicate that an earthquake originates at some depth greater than 30 miles below the surface of the earth.

*DEW line:* Distant Early Warning line. System of radar stations established in the most northerly areas of the North American Continent to provide early warning of possible impending attack by aircraft.

*Direct optical:* Detection of a nuclear explosion by use of instruments (photo multipliers) sensitive to short pulse of visible light emitted by the explosion as a result of incandescence of the matter in the device.

*Electromagnetic:* (Detection of) radio frequency waves caused by a nuclear explosion and propagated from the point of the explosion to great distances.

*Electromagnetic induction detectors:* An instrument which radiates a low-frequency electromagnetic field and is sensitive to any distortion in this field due to the presence of conducting material such as iron or copper pipe, wire, landmines, etc.

*First motion criteria:* Criteria (or tests) by which the nature of the source of a seismic disturbance is established. In principle, explosions will cause the first movement of the earth to be in a direction away from the source. Earthquakes, on the other hand, can cause the first movement of the earth to be in a direction toward the source. Specific criteria are phrased in terms of how much larger than the noise the apparent motion toward the source can be considered to be a reliable indication of an earthquake.

*Fluorescence:* Detection of a nuclear explosion by use of instruments sensitive to the short pulse of visible light emitted by the gases of the upper atmosphere in fluorescence caused primarily by absorption of energy from X-rays radiated from a nuclear explosion at high altitude or in space.

*Gamma ray:* Electromagnetic radiation similar to X-rays but generally more penetrating.

*Hardtack II:* A series of underground nuclear explosions conducted in the Nevada test area in the fall of 1958. The principal underground explosions were Blanca (19 kilotons) and Logan (5 kilotons). The seismic data from these explosions provide the basis of most estimates on the detection capabilities of the control system.

*Heat-absorbing material:* Materials such as powdered graphite may be distributed throughout the cavity in which a nuclear device has been mounted for the purpose of providing decoupling. Part of the energy of the explosion will be absorbed in vaporizing the powdered graphite and would theoretically reduce the pressure from the explosion on the walls of the cavity.

*High frequency seismograph:* A seismograph sensitive to seismic waves of from several cycles per second to about 100 cycles per second (principally used in prospecting for oil).

*Hydroacoustic:* (Detection of) pressure waves caused by an underwater nuclear explosion which are propagated through the ocean waters from the point of the explosion to an underwater microphone usually called a hydrophone.

*Intermediate period seismograph:* This term usually covers seismographs sensitive to seismic waves of periods between 2 and 10 seconds.

*Ionospheric radar:* See "Backscatter radar."

*Kilometer:* 1,000 meters (0.621 statute mile).

*Kiloton:* Explosive energy release corresponding to 1,000 tons of the chemical high explosive, TNT. The bomb detonated at Hiroshima

near the conclusion of World War II was equivalent in size to 20 kilotons of TNT.

*Long period seismograph:* A seismograph sensitive to seismic waves of natural periods greater than 10 seconds.

*Magnetometer:* An instrument for measuring the natural magnetic field of the earth to discover any distortion in this field by manmade ferrous articles (i.e., equipment, pipes, etc.) or the permanent magnetism which may exist in manmade instruments or natural ferromagnetic materials.

*Magnitude:* An arbitrary scale used by seismologists according to size. The scale is so arranged that a magnitude 6 earthquake is 10 times larger than one of magnitude 5; a magnitude 5 is 10 times larger than magnitude 4, etc.

*Megaton:* Equivalent of 1,000 kilotons or 1 million tons of chemical explosive (TNT).

*Microseisms:* Very small vibrations in the earth's surface layers caused by ocean waves beating on the shore and by the action of turbulent wind on the earth.

*Nuclear debris sampling:* Detection of nuclear explosions by collection of fine debris particles from the atmosphere by airborne or ground-air filtering equipment and analysis by radiochemical techniques.

*Neutron:* One of the elementary particles found in the nucleus of all atoms except the most abundant form of hydrogen. In the chain reaction fission process of a nuclear explosion, two to three neutrons are emitted for each uranium atom fissioned and are available to induce fission of more uranium atoms. These neutrons have high initial energies and are transmitted to great distances where they can be detected with suitable equipment.

*Nevada tuff:* A weakly cemented, rather crumbly rock, formed from volcanic ash. The underground nuclear explosions of Hardtack II, as well as the Rainier explosion, occurred in this rock, which is somewhat elastic and produces stronger seismic signals from nuclear explosions than are produced by the same size explosions in salt and granite.

*Overburden:* When a hole is excavated deep underground for the pourpose of decoupling a nuclear explosion, the earth or rock between the hole and the surface produces an external pressure on the walls of the hole in proportion to the depth. The amount of earth above the hole, usually measured in feet, is referred to as the "overburden."

*Peak signal:* The maximum amplitude of motion of the seismograph in response to a nuclear explosion or earthquake.

*Piggyback:* Experimental equipment for making measurements in space which is added to a missile or satellite originally planned for other types of measurements.

*Rainier coupling:* The Rainier shot (1.7 kilotons) conducted 900 feet underground in intimate contact with a rocklike material known as Nevada tuff on September 19, 1957, was estimated to have transmitted about 2 percent of its energy into seismic waves. This observed degree of energy transformation from the explosion to seismic waves in the earth (coupling) has been taken as a standard for subsequent calculations of seismic signals generated by underground nuclear explosions.

*Reflection shooting:* The process of studying the rock strata deep under the surface (20,000 feet) by recording on an array of surface seismographs the seismic waves from small chemical explosions which travel downward and are reflected back to the surface on near vertical paths.

*Refraction shooting:* The process of studying the detailed character of the strata underlying the earth's surface by firing small charges of chemical explosives and studying the seismic waves from the explosion which proceed downward through strata in question, are refracted (bent) along the strata and refracted again back upward to an array of seismometers where they are detected and recorded.

*Seismograph:* An instrument for detecting and recording small vibrations in the earth's crust. The detector portion, called a seismometer, usually consists of a mass suspended from a frame either by springs or as a pendulum, in such a manner as to tend to remain in one position while the earth-mounted frame moves with the earth. The relative motion of the frame and mass is usually magnified and recorded as a seismic disturbance either natural or manmade.

*Seismometer:* The detector portion of a seismograph which may be located in a deep hole or on remote outcrops as in array emplacements and its motion being transmitted as electrical pulses through many miles of cable to the recording instrument.

*Shielded detonation:* Detonations of nuclear explosives in space can be "shielded" by placing thin spherical or cylindrical sheets of lead or other material around the nuclear device. This shield reduces the amount of radiation from the nuclear explosion and hence reduces the range of detection. Shields are particularly effective for thermal X-rays.

*Short period seismograph:* A seismograph sensitive to seismic waves of about 2 seconds or less (of considerable significance in detecting nuclear explosions).

*Signal-to-noise:* In recording the vibrations produced in the earth by a nuclear explosion it is necessary that the size of the signature from the explosion be larger than the microseismic noise on the record to permit the signature to be identified. The ratio of the amplitude of the signal to the amplitude of the noise is called the "signal-to-noise" level.

*Strategic nuclear weapons:* Those nuclear weapons ranging in yield of approximately 50 kilotons and more, to include the megaton yields. This class is often referred to as "high yield weapons."

*Tactical nuclear weapons:* Those nuclear weapons ranging in yields below 20 kilotons. This class is often referred to as "low yield weapons."

*Tamped shot:* An underground explosion detonated in close contact with the surrounding earth or rock so as to transmit to the earth or rock the largest possible fraction of its energy. (Alternative to maximize coupling.)

*Technical Working Group I:* Of the Conference on the Discontinuance of Nuclear Weapons Tests, the Technical Working Group on the Detection and Identification of High Altitude Nuclear Explosions (June–July 1959).

*Technical Working Group II:* Of the Conference on the Discontinuance of Nuclear Weapons Tests, the Technical Working Group on

the Detection and Identification of Underground Nuclear Explosions (November–December 1959).

*Thermal X-ray:* Electromagnetic radiation due to the extremely high temperature of the nuclear device fireball. Similar to normal X-rays but much less penetrating.

*Threshold:* A seismograph of a given sensitivity placed a known distance from an underground explosion or earthquake will record relatively large earthquakes and underground explosions. As the magnitude of the earthquake or equivalent yield of the explosion is reduced it becomes more and more difficult to detect the signature of these events on the seismograph. Eventually one reaches a "threshold" which is defined as the smallest earthquake or underground nuclear explosion which can be clearly detected.

*Velocity meters:* Strong motion instruments which are so designed as to record the velocity of earth motion relative to the suspended mass of the instruments rather than measure the actual displacement of the earth.

## APPENDIX 2

### PUBLIC HEARINGS ON NUCLEAR TEST DETECTION (APRIL 19–22, 1960)

LIST OF WITNESSES IN ORDER OF APPEARANCE

1. Dr. Harold Brown, Lawrence Radiation Laboratory, Livermore, Calif.
2. Dr. Wolfgang H. Panofsky, High Energy Physics Laboratory, Stanford University, Palo Alto, Calif.
3. Dr. Richard Latter, Rand Corp., Santa Monica, Calif.
4. Dr. Carl F. Romney, Headquarters, USAF, Air Force Technical Applications Center, Washington, D.C.
5. Dr. Albert R. Latter, Rand Corp., Santa Monica, Calif.
6. Mr. L. P. Meade, Phillips Petroleum Co., Bartlesville, Okla.
7. Dr. Edward Teller, Lawrence Radiation Laboratory, Livermore, Calif.
8. Dr. Hans Bethé, Physics Department, Cornell University, Ithaca, N.Y.
9. Dr. Jack E. Oliver, Lamont Geological Observatory, Columbia University, New York, N.Y.
10. Dr. Alvin C. Graves, Los Alamos Scientific Laboratory, Los Alamos, N. Mex.
11. Dr. Richard E. Roberts, Carnegie Institution, Washington, D.C.
12. Dr. Jay Orear, Physics Department, Cornell University, Ithaca, N.Y.
13. Dr. Roland Beers, seismic consultant, Troy, N.Y.
14. Dr. Dean S. Carder, Chief Seismologist, U.S. Coast and Geodetic Survey. Washington, D.C.
15. Dr. Harold Urey, University of California, Scripps Institute of Oceanography, La Jolla, Calif.
16. Dr. Charles E. Violet, Lawrence Radiation Laboratory, Livermore, Calif.
17. Dr. Richard M. Foose, Department of Earth Sciences, Stanford Research Institute, Menlo Park, Calif.
18. Dr. Richard Peterson, United Geophysical Corp., Pasadena, Calif.
19. Mr. Frank Coker, United Electro-Dynamics Corp., Pasadena, Calif.
20. Dr. B. P. Leonard, Space Technology Laboratory, Los Angeles, Calif.
21. Dr. Richard Taschek, Los Alamos Scientific Laboratory, Los Alamos, N. Mex.
22. Mr. Carleton M. Beyer, Advanced Research Projects Agency, Department of Defense, Washington, D.C.
23. Dr. Gerald W. Johnson, Lawrence Radiation Laboratory, Livermore, Calif.
24. Dr. Herbert Jehle, George Washington University, Washington, D.C.



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